RECENT ENGINEERING IMPROVEMENTS OF THE CLYDE NAVIGATION.

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In a previous paper presented to the Edinburgh Meeting of this Institution in 1887 the author traced the improvement of the Clyde Navigation above Port Glasgow to that date. The object of the present paper is to continue the subject, by giving particulars of the dredging machinery, and especially of the recent additions thereto, and the quantities and cost of the dredging in the harbour and river, and the depositing of the dredged material, during the seven years from 1st July 1887 to 30th June 1894; and to describe in some detail the harbour of Glasgow and its equipment at the present day. See Plates 98 to 101.

Dredging.—The improvement of the Clyde above Port Glasgow since 1887 has consisted solely in deepening and widening by dredging. During these seven years the total quantity of material dredged in the harbour and river, and in the construction of the docks and removal of silt from them, was 11,401,978 cubic yards, of which 5,723,157 were deposit, and 5,678,821 were new material. In addition there were excavated by men 21,726 cubic yards, bringing up the total to 11,423,704, of which 441,850 were deposited on land, 9,523,141 in Loch Long, 1,449,243 in the sea three miles S.S.W. from Garroch Head, which is about 46 miles from Glasgow, and 9,470 cubic yards were deposited in other parts of the river and Firth or were otherwise disposed of. The details are given in the accompanying Tables 1 and 2. In Plate 101 are shown the sites of depositing in Loch Long and outside Garroch Head.

TABLE 1.—*Dredging and Excavating.*

Year ending 30 June.		1888	1889	1890	1891	1892	1893	1894	Totals.
		Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.
In Harbour and Docks	D	282,960	403,804	323,348	394,624	531,672	366,998	974,523	3,277,929
	N	18,720	117,836	43,276	46,848	411,824	1,168,484	1,032,017	2,839,005
In River, west of Kelvin	D	305,664	359,164	505,676	509,192	292,424	124,788	272,896	2,369,804
	N	711,440	602,236	485,292	288,856	239,824	66,856	14,232	2,408,736
On Loan account — In Harbour	D						1,472	32	1,504
	N			2,640	16,800	7,520			26,960
On Loan account — In River	D	17,280		15,840	5,920		17,600	17,280	73,920
	N	76,840	47,520	37,440	31,440	115,720	95,160		404,120
Totals Dredged		1,412,904	1,530,560	1,413,512	1,293,680	1,598,984	1,841,358	2,310,980	11,401,978
Excavated by men at various places		2,584	2,192	1,600	896	4,968	2,498	6,988	21,726
Totals Dredged and Excavated		1,415,488	1,532,752	1,415,112	1,294,576	1,603,952	1,843,856	2,317,968	11,423,704

D = Deposit. N = New material.

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TABLE 2.—*Depositing of Material Dredged and Excavated.*

Year ending 30 June.	1888	1889	1890	1891	1892	1893	1894	Totals.
	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.
On Land	70,168	62,112	45,392	57,840	65,592	86,176	54,570	441,850
In Loch Long	1,340,840	1,470,160	1,367,840	1,236,736	1,538,200	1,540,120	1,029,245	9,523,141
Off Garroch Head	—	—	—	—	—	217,420	1,231,823	1,449,243
In other parts of River and Firth, or otherwise disposed of	4,480	480	1,880	—	160	140	2,330	9,470
Totals Deposited	1,415,488	1,532,752	1,415,112	1,294,576	1,603,952	1,843,856	2,317,968	11,423,704

The cost of dredging and depositing by hopper barges, and of laying dredgings on land, during the same seven years—comprising wages, coals, stores, repairs of plant &c., but not including interest on cost of plant, or depreciation—was as follows, being equal to 6·396 pence per cubic yard:—

Year ending 30 June.	Cost. £	s.	d.	Quantities Dredged. Cubic Yards.
1888	44,128	6	6	1,412,904
1889	41,520	3	3	1,530,560
1890	39,914	0	7	1,413,512
1891	38,611	0	0	1,293,680
1892	40,268	13	7	1,598,984
1893	49,146	11	2	1,841,358
1894	50,292	6	2	2,310,980
	£303,881	1	3	11,401,978

Up till 1862 the whole of the dredged material was loaded on punts, carrying 8 cubic yards; and from these it was discharged, chiefly under contract, upon land adjoining the river, and also by throwing overboard on both shores at certain places below Dumbarton Castle, Plate 100. The average cost for thus depositing harbour dredgings, including the use of punts, towing &c., was 10·04 pence per ton, or $12\frac{1}{2}$ pence per cubic yard. The total quantity dredged for the year ending 30 June 1862 was 569,016 cubic yards, all of which was deposited on land.

In August 1862 depositing in Loch Long, within an area of 428 acres laid down by the Admiralty on a chart, Plate 101, was inaugurated by a steam hopper-barge built by Messrs. William Simons and Co., Renfrew, of 240 cubic yards capacity and 35 nominal horse-power. The barges were from time to time increased in number, until in August 1877 the fleet consisted of eighteen, four having a capacity of 240 cubic yards each, and fourteen of 320 cubic yards. The other dredging plant at that date consisted of five steam dredgers from 25 to 75 nominal horse-power, one tug steamer, two diving bells, and 250 punts. The total quantity dredged during the year ending 30 June 1877 was 965,468 cubic yards. In August

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1889, No. 6 dredger was run into, sunk, and wrecked in the river, below Bowling; and was not replaced until 1892, when a single-ladder dredger was procured, 200 feet long by 37 feet broad and $12\frac{1}{2}$ feet deep, with a hull of steel, thirty-five buckets of 22 cubic feet capacity each, capable of lifting at the rate of 600 tons per hour in 40 feet depth of water, and lighted throughout by electricity; and also two twin-screw hopper-barges of 1,000 tons capacity each, which were followed in 1893 by four twin-screw hopper-barges of 1,200 tons capacity each. The dredger and four of the hopper-barges were supplied by Messrs. Fleming and Ferguson, of Paisley, and the other two hopper-barges by Messrs. William Simons and Co., of Renfrew. This dredger, named "Cairndhu," is shown in Plates 102 and 103, and one of the 1,000-ton hopper-barges in Plate 104; and detailed descriptions of these are given in appendix 1, pages 425–428.

The provision of this powerful dredger was rendered necessary for the expeditious dredging out of Cessnock Dock; and the hopper-barges were required in consequence of the Board of Trade prohibiting the Clyde Trustees from continuing to deposit any harbour and river deposits in Loch Long, and requiring that these should be deposited seaward of Garroch Head, Plate 101; they consented however to the continuance of depositing in Loch Long the new material dredged out of Cessnock Dock. The total quantity of material deposited in Loch Long by the Clyde Trustees up to 18 March 1893, when the harbour and river dredgings ceased to be deposited there, amounted to fully 30,000,000 cubic yards. The total quantity dredged during the year ending 30 June 1894 was 2,310,980 cubic yards, and 6,988 cubic yards were excavated by men, making 2,317,968 cubic yards altogether. Of this total only 54,570 cubic yards were deposited on land, and of the remainder 1,029,245 cubic yards were deposited in Loch Long, 1,231,823 cubic yards in the Firth, three miles S.S.W. of Garroch Head, and 2,330 cubic yards in other parts of the river and Firth, or otherwise disposed of.

The lighting of the channel of the Clyde between Glasgow and Port Glasgow is by three light-towers, at Dalmuir, Rashielee, and Donald's Quay, all above Bowling; by a beacon light at Longhaugh Point, one mile below Bowling; by Dumbuck lighthouse, about two miles below Bowling; by Garmoyle lightship, one mile below Dumbarton Castle; by Cardross light, one mile above the Clyde Trustees' boundary at Port Glasgow; and by seven lighted buoys on the south side of the channel, between Dumbarton and Port Glasgow; the whole of these lights are lit by Pintsch's gas. The Clyde from Port Glasgow to the sea is lighted by the Clyde Lighthouses Trust, under whose care the estuary is to the Cumbrae Heads, 22 miles below Greenock.

Progress of Glasgow Harbour since June 1887. *Quays.*—The quayage of the harbour, Plate 98, including Kingston Dock and Queen's Dock, and Cessnock Dock so far as in use, is now 7 miles in length, all of which is tidal, with a water area of 185 acres. The extension of the harbour has been from Glasgow Bridge downwards; and until 1865 the sides of the river afforded sufficient room for increasing the quayage, which consisted generally of stone superstructures, founded not much below the then level of low water on bearing and sheet piles, or on planking with sheet piles in front, and for a short length on boulder clay. The piles for the early quays were round home timber from 12 to 15 feet long, giving an available depth in front of the quays at low water of from 5 to 6 feet; and for the later quayage the piles were of sawn red pine, the bearing piles being generally 12 inches square and ranging in length from 20 to 25 feet, and the sheet piling 6 inches thick and from 15 to 17 feet in length.

The rapid lowering of low-water level, due to the deepening of the river from deep water upwards, and the dredging in front of the quays to suit the increasing draught of vessels, brought down a number of the earlier quays, which were generally replaced by timber wharfing. Others of the quays were prevented from falling by longer and stronger sheet-piling being driven in front of the original sheet-piling, and tied back with iron rods, generally to piles driven into the solid ground behind. Later on, the more modern quays had for the same reason to be treated in a similar but more thorough manner: the new sheet-piling was of creosoted pitch pine 12 inches thick and ranging from 30 to 45 feet in length, driven in bays of three and four piles each, which were tied back by iron rods to heavy blocks of masonry. By this means, notwithstanding the still lowering level of low water, a depth of 18 feet at low water was obtained without injury to the quays.

Docks.—In 1867 the first dock was opened, called Kingston Dock, Plate 98, having 5⅓ acres of water space and 830 lineal yards of quayage. It was substantially wharfed all round, with sheet piling in front 35 feet long by 11 inches thick, and main piles ranging from 42 to 50 feet long by 12 inches square, giving a depth of 10 feet at low water in front of wharf, and 14 feet in centre of dock.

Cylinder Foundations.—The ground in which the quay walls and docks have to be constructed consists chiefly of quicksand and water-bearing gravel. Except in one solitary instance in Queen's Dock, rock is not reached till a depth of from 70 to 80 feet below cope level. In 1870, in order to meet the increasing depth demanded by the ships frequenting the port, and also in order to secure a permanency which quay walls founded on bearing and sheet piles did not afford, the author adopted for the substructure of the walls a single row of brick cylinders, each 12 feet external diameter and 7 feet 4 ins. internal diameter, tongued and grooved into one another, Plate 105. These after being sunk were filled with concrete; and upon them was built a brick superstructure coped with granite, and tied back to blocks of masonry behind by iron tie-rods, 2½ ins. diameter and 65 feet long, placed 24 feet apart. This construction was followed two years later by triple groups of Portland-cement concrete cylinders, 9 feet 7½ inches diameter outside and 5 feet 9½ inches inside, filled with concrete and sand, for the substructure; and for the superstructure concrete rubble, faced with freestone ashlar, and coped with granite. In recent years the freestone ashlar has been succeeded by concrete ashlar made in moulds, and built like ordinary ashlar. The adoption of these cylinders for the substructure has obviated the great expense of constructing coffer-dams and digging trenches to found the walls in, and of heavy pumping; by means of diggers the cylinders were sunk without pumping, and were then filled with concrete.

The single row of brick cylinders with brick superstructure was carried out in the construction of the first 403 yards' length of Plantation Quay, Plate 105. The cylinders were 35 feet 7 inches long, terminating at 2 feet 8½ inches above low water. In order to carry the superstructure, the voids between the tops of the cylinders were lintelled over with cast-iron plates in the front, and with freestone blocks at the back. The remaining length of 297 yards of this quay wall, Plate 106, was carried on groups of triple concrete cylinders, 12 feet diameter outside and 7 feet 4 inches inside, and 29 feet 8½ inches long, with their tops terminating at 3 feet below low water. Chock piles 9 inches square were driven to close up the joints between the successive groups of cylinders; and the voids between the cylinders were lintelled over with cast-iron and freestone lintels. The superstructure consisted of brick facing and concrete rubble backing.

Queen's Dock.—In 1846 an act was obtained for the construction of a dock on the north side of the river, within the precincts of the harbour, Plate 98; but it was not commenced until 1870, in which year an act was obtained for a larger dock than that authorised in 1846. This dock, called the Queen's Dock, has a water area of 33¾ acres, with 20 feet depth at low water; the quayage area is 26⅔ acres, and the quays are 3,334 yards or 1·9 mile in length. It comprises three basins: the north, 1,866 feet long by 270 feet wide; the south, 1,647 feet long by 230 feet wide, with a quay between them 195 feet broad; and an outer basin, 1,000 feet long and 695 feet wide at its widest part. The dock is tidal, and is approached by an entrance 100 feet wide, which is crossed by a swing bridge capable of carrying a rolling load of 60 tons on any part of its roadway.

Concrete cylinders, Plate 109, were adopted for the substructure of all the quay walls of the dock, with the exception of some 800 yards of wall of the usual description, which was founded on concrete blocks laid on boulder clay, Plate 107; and where strong coarse gravel or rock occurred, liquid concrete was substituted for the concrete blocks, by which means all the holes and inequalities in the surface of the gravel and rock were thoroughly filled in. At two or three places, where pockets of clay were encountered, piling was adopted, Plate 108. Concrete cylinders of a similar description, with occasional variations to suit special circumstances, have been adopted for the 5,213 yards or nearly three miles length of quays constructed in the extension since 1870 of the river quayage, and for the quays of Cessnock Dock, now in course of formation. A description of those used in the construction of Queen's Dock will therefore suffice for all.

Concrete Cylinders.—The cylinders for carrying the quay walls are triple, Plate 109. They were made in rings 2 ft. 6 ins. deep by 1 ft. 11 ins. thick, in movable wooden moulds on a platform. The concrete consisted of five of gravel or broken stones and sharp sand to one of Portland cement of the strongest description, mixed together by steam power in mixers designed for the purpose, water being added to bring the mass into a plastic state. To facilitate lifting, the rings were divided into three and four segments alternately, Fig. 24, so as to break bond when built into the cylinders. The division was effected in a simple manner: malleable-iron dividing plates 3–8ths inch thick were placed radially across the empty wooden moulds in the positions required; the concrete was then filled in, and well punned with hammers weighing 25 lbs., so as to secure homogeneity and a smooth surface. Twelve hours afterwards the dividing plates were withdrawn, and two days later the wooden moulds themselves; and in periods varying from nine days in hot summer weather to three weeks in the rains of winter the rings were ready for removal and building. The volume of one ring complete was $10\frac{1}{2}$ cubic yards, and the weight 18 tons, the heaviest segments weighing about 6 tons each.

The cylinders were each built up of ten rings, each 2 ft. 6 ins. deep, and one ring 1 ft. 6 ins. deep, making with shoe 28 feet total height. The bottom ring, differing from the others, is called a corbelled ring, because it is made less in thickness all round the bottom edge, in order to fit into a cast-iron shoe, Fig. 23, and is tapered inwards and upwards to the full thickness of 1 foot 11 inches. The shoe is 2 feet deep, Plate 110, of 1 inch metal, and of the same external size and shape as the rings; the under side of the bottom ring rests on a shelf in the shoe, 6 inches below the top edge of the shoe. This shelf is formed by an inner ring of cast-iron, 1 inch thick, projecting at the top 12 inches inwards from the outside of the rim of the shoe, and tapering outwards to the bottom of the shoe, where it joins the outer ring, thus forming a cutting edge to the bottom of the shoe; the wedge-shaped space between the outer and inner ring, Figs. 26 to 29, is filled up with concrete. The shoe is under the outer circumference only of the corbelled ring, the inner part of the ring being unshod. The shoe weighs about $4\frac{1}{2}$ tons, and was made in six parts, Fig. 25, for convenience of placing in the trench, which was excavated along the line of the quay wall. The bottom of the trench was about $4\frac{1}{2}$ feet below low-water level, where it was made 19 feet wide; the sides sloped upwards with a batter of $1\frac{1}{2}$ horizontal to 1 perpendicular, as shown by the dotted lines in Fig. 23. The necessary staging was erected to carry the travelling cranes and digging apparatus. On the bottom of the trench the shoes were placed exactly along the line of the quay wall, and the corbelled ring being placed on the shelf in the shoe was bolted to it by thirteen $1\frac{1}{4}$-inch bolts; a malleable-iron ring, 5 inches broad by $\frac{1}{2}$ inch thick, was sunk into the top surface of the corbelled ring, in which the recess for this plate and the holes for the bolts passing through the ring had been made in the moulding of the concrete ring. The remaining ten rings forming the cylinder were set one on the top of another in Portland cement, in three and four segments alternately, so as to break bond. The cylinders being triple, or in groups of three, were placed in the trench so as to dovetail into one another, one in front and two behind, alternating with two in front and one behind. The sides of the groups where they pressed against each other were flattened for a breadth of 5 feet, so as to ensure a good bearing.

When the building up of the rings forming one group of cylinders was completed to the full height of 28 feet, the sand and gravel were dug out simultaneously from within each of the three cylinders, by means of excavators specially designed for that purpose. From 300 to 400 tons of cast-iron segmental weights of the same shape as the rings were generally required to force each group of cylinders down to the required depth, which is 50 feet below the cope level of the quay; the tops of the cylinders finish about 3 feet below low-water level. The average rate of sinking was about one foot per hour; in good working sand as much as three feet per hour was attained. When the group had been sunk, each cylinder was cleaned out by means of the excavators to the level of the bottom of the shoe, and was then filled to the top with Portland-cement concrete. On this foundation the quay wall is built. In order effectually to close up the apertures between the adjoining groups of cylinders, a timber chock-pile, 25 feet long by 9 inches square, was driven behind angle-ways, so that a sharp corner bears hard against each of the adjoining cylinders.

The walls are of concrete rubble, and many of the stones weigh from two to three tons each. The walls are faced with freestone ashlar, in courses ranging from 18 to 15 inches thick; the stones are not less than 4 feet long by 2 feet broad on the beds, and the headers not more than 10 feet apart from centre to centre. The cope is of granite, $3\frac{1}{2}$ feet broad by 17 inches thick, in lengths of not less than 4 feet; and the mooring paals or bollards, which are 32 feet apart from centre to centre, are built into the wall immediately behind the cope.

Swing Bridge.—The swing bridge across the entrance to the dock is carried on a foundation probably unique in the annals of swing-bridges, namely on a group of twelve concrete cylinders, Plates 112 to 114, each 9 feet external diameter, 29 feet long and 23 inches thick, resting on cast-iron shoes similar to those used for the quay-wall foundations. The cylinders were sunk in the manner already described; and after they and the interstices between them had been properly cleaned out, all the voids were filled to the top with concrete, chock-piles being driven where required. On the centre of the rectangular foundation thus formed, 36 feet 4 inches long by 27 feet 3 inches broad and 29 feet deep, a stepped ashlar pier was erected 16 feet square at the bottom, 10 feet square at the top, and 7 feet high surmounted by a block of granite 7 feet square and $3\frac{1}{2}$ feet deep, on which the centre lifting-press rests. The pier is surrounded by concrete rubble, the whole forming a mass of masonry 36½ feet long by 32½ feet broad and 10½ feet high up to the level of the floor of the bridge press-chamber. The centre pier sustains a weight of 800 tons. Considerable difficulty was experienced in securing stable foundations for the hydraulic rams for working the bridge, and also for the capstans and the side walls of the bridge pit, in consequence of the ground being loose and insecure where these had to be placed. The difficulty was overcome by using single concrete cylinders placed apart, and spanned between by brick arches, Plate 113. The bridge is 181½ feet long by 40½ feet wide; the length overhanging the centre of centre press is 126½ feet, part of which spans the 100 feet opening. The swing-bridge and hydraulic machinery have been in daily use since 18 September 1877, when the Queen's Dock was formally opened by the admission of the Anchor line s.s. "Victoria," 369½ feet long by 40 feet broad and 2,081 tons register.

On the completion of Queen's Dock, the north and west quays, together 3,155 feet in length by 91⅓ feet and 95 feet in breadth respectively, were equipped with four 19-ton hydraulic fixed cranes for the shipment of coal, and with one 30-cwt. and two 35-cwt. portable hydraulic cranes for the discharge of ore and the loading and discharge of promiscuous cargo. These were subsequently supplemented by eight 5-ton portable steam-cranes, to meet the increasing business. The hydraulic installation, including hydraulic cranes and the swing bridge at the dock entrance, together with the hydraulic machinery for working it, was supplied by Sir W. G. Armstrong and Co. The hydraulic pumping engines have just been much increased in power and efficiency by compounding the high-pressure pumping engine, which has been done by the Glenfield Co., Kilmarnock. The other engine, which was supplied by Sir W. G. Armstrong and Co. about four years after the original installation, was compound from the first. A second accumulator has also been supplied and erected by the Glenfield Co., in a brick tower situated about the centre of the north quay; it is supplied by pipes of 5-inches bore direct from the two pumping engines. The four coaling cranes have also recently been made much more effective and speedy in their action, by substituting direct-acting rams in place of the hydraulic engines for hoisting and lowering, and by lengthening the jibs so as to command the hatchways of the largest steamers trading with the port. The cranes are now each capable of shipping 25 wagons of coal per hour, each wagon loaded with 15 tons.

Cessnock Dock.—To increase the stability of the quay walls of Cessnock Dock, tie rods $2\frac{1}{2}$ inches diameter and 60 feet long were put in, fixed to blocks of concrete masonry 12 feet long by 6 feet broad and 8 feet deep, Fig. 36, Plate 115. Where a depth of 20 feet at low water is afforded, the tie rods are 64 feet apart; and where there is 25 feet depth at low water, they are 32 feet apart. Where 28 feet depth at low water was desired, the single row of triple cylinders was supplemented behind by a row of twin cylinders, 9 feet $7\frac{1}{2}$ inches diameter outside and 5 feet $9\frac{1}{2}$ inches inside, Plate 116; and the tie rods were increased to $3\frac{1}{2}$ inches diameter and 70 feet length, and placed 64 feet apart.

The total water area of Cessnock Dock when completed will be $34\frac{2}{3}$ acres, the area of quayage $36\frac{2}{3}$ acres, and the length of the quays 3,760 yards or 2·13 miles. The dock will comprise an outer or canting basin, and three branch basins. The general thickness of the superstructure of the walls is 16 feet at bottom, on the top of the cylinders, and $6\frac{1}{2}$ feet at top; but where the substructure contains also a single row of twin cylinders 9 feet $7\frac{1}{2}$ inches diameter, behind the front row of triple cylinders, the thickness at bottom is 26 feet, and at top $6\frac{1}{2}$ feet. The whole of the work is being executed administratively; the iron shoes are supplied on contract, as are also all stones, the dressed granite cope and other granite ready for building, cement, timber, &c. Including tie rods and excavation of trenches, the cost of the walls to give 20 feet depth at low water has been £80 per lineal yard, to give 25 feet £90 per lineal yard, and to give 28 feet depth £120 per lineal yard.

At the annual inspection of the harbour and river on 27th June last, the first instalment of nine hydraulic cranes and the machinery for giving power to them, supplied by Messrs. Fullerton, Hodgart, and Barclay, of Paisley, were inaugurated. The machinery consists of two separate sets of three single-acting 5-inch pumps, worked by two triple-expansion surface-condensing engines of the most improved design, having cylinders 15 and 22 and 36 inches diameter by 24 inches stroke. The working pressure is 150 lbs. per square inch. The pumps are capable of delivering 200 gallons per minute against a pressure of 750 lbs. per square inch. The engines are fitted with automatic starting gear and high-speed governor and valve. Steam is supplied by two marine boilers, each 11 feet diameter by 10 feet long, with two furnaces in each, 3 feet 2 inches diameter, tested to 300 lbs. per square inch. The boilers are fed by two Cameron pumps, the feed-water being drawn from a large tank under the floor of the engine house, into which the air-pump discharge is led. The accumulator ram is 20 inches diameter with 20 feet stroke. The load case is 12 feet diameter by 20 feet deep, loaded with sand to give a pressure of 750 lbs. per square inch. A safety-valve and regulating gear to the throttle-valve in the steam pipe are provided. Main pressure-pipes of 7 inches diameter, and 8-inch return-water pipes, have been laid from the accumulator to a point in line with the south quay of the north basin; and from there 4-inch pressure and 5-inch return-water pipes branch off, and are led along the south quay in a tunnel constructed in the dock wall. From these pipes branches are taken to hydrant boxes spaced 30 feet apart, in which are stop-valves on branches to the cranes; to the latter branches the cranes are connected by portable flexible piping. A large overhead water-tank is fitted in the boiler house for storing the return water, which is led thence by suction pipes to the pressure pumps. A well has been formed near the north-east corner of the centre basin, connected therewith by a pipe 2½ feet diameter, passing through the dock wall and having a sluice valve inside the well for shutting off the dock water, so as to admit of repairs to the retaining valves and rose boxes. Two 7-inch pipes are led from this well, one to each of the engines, for supplying water for circulating through the condensers. The water is drawn by the circulating pumps, discharged through the condensers, and passes through an 18-inch pipe to a sewer leading by way of Plantation quay into the river. Into this sewer is also led the blow-off pipe from the boilers.

The cranes are capable of lifting 35 cwts. in ordinary working, from 40 feet below cope of quay wall to 25 feet above it, a total lift of 65 feet. The jibs have a range of 29 feet, and project about $27\frac{1}{2}$ feet beyond the face of the quay wall. The cranes are mounted on carriages made of steel plates, and are movable along the whole length of the south quay on rails spaced 14 feet apart. The lifting and slewing speeds are 300 feet and 400 feet per minute respectively. Each crane has two cabins, one on each side of the carriage; and in each cabin is a set of handles for controlling the hoisting and turning motions. The attendant can thus work the crane from whichever cabin is most conveniently situated for the loads to be lifted. At present there are nine of these cranes; but provision has been made in the engine house for power to work thirty-five of this kind, together with five cranes capable of lifting 5 tons each, and five coaling cranes of a capacity of 20 tons each.

With the two engines now fitted there is a large surplus of hydraulic power at present; but when the equipment is gradually extended, as the construction of the dock proceeds, additional power will be necessary; and arrangements have been made in the new buildings for five sets of engines, similar to the two now completed; the seven it is expected will give an ample margin of power to allow of one set of engines being laid off occasionally for overhauling when necessary. The buildings for the hydraulic pumping machinery &c., which are from the design of Messrs. Burnet, Son and Campbell, Glasgow, are of a pleasing appearance, without unnecessary ornamentation, in red pressed brick with red stone facings; they consist of engine and boiler house, chimney 180 feet high, and accumulator tower.

Crane Seat and 130-ton Crane.—A description of the recently constructed crane seat and crane, erected on the west quay of Cessnock Dock, and tested to 150 tons, will convey a general idea of their character. As shown in Plates 117 and 118, the external dimensions of the seat are 40 feet square, and it rises 20 feet above the quay level, Fig. 40. The cylinders of the triple groups and twin row behind, which form the substructure of the quay wall, with the addition of three triple cylinders behind the twin cylinders, together form the substructure of the seat, Fig. 41. All these cylinders are 9 feet 7½ inches diameter outside and 5 feet 9½ inches inside and 49 feet in length; they terminate 7 inches above low-water level of ordinary spring tides, and above them the superstructure rises to a height of 38 feet 10 inches; but while the face of the quay wall has a batter of 1 in 12 from the top of the cylinders, the seat is carried up plumb, Fig. 40. It consists of concrete rubble hearting, faced with concrete ashlar in courses, with granite quoins at each of the four corners, and a granite cope 3 feet thick, with a minimum breadth of 6½ feet on each side and 14 feet at the corners. The total weight of masonry above the concrete cylinders is 4,300 tons.

The framing, shafting, and jib of the crane are of mild steel; the gearing, so far as necessary, of cast steel; and the crane revolves on steel live-rollers working on a steel pathway, Fig. 42, Plate 118. The centre of the crane is a strong massive casting, Plate 119, weighing 9 tons, held down by six steel bolts, each 33 feet 9 inches long and 5 inches diameter, weighing together 8 tons; they are fixed to six washer-plates, each 6 feet square and weighing 13 tons, which are built at equal intervals into the seat at a depth of 30 feet below the top of the seat. A brick-lined tunnel, 2½ feet wide, 11 feet radius at its centre, and 6 feet high, with a manhole, and an approach of same size from one side of the crane seat, Fig. 43, give access to the washer-plates for fixing the cotters in the bottom ends of the bolts. The upward passages for the bolts were formed during the construction of the seat. In the centre casting is placed the steel centre pin, 17 inches diameter, weighing 6 tons, having a forged head, Plate 119. The upper end of the pin carries a steel clip, having on its under surface a steel pathway, between which and a similar pathway fixed in the revolving frame of the crane move sixteen live rollers, Plate 120, for reducing the friction to a minimum. The diameter of the main-roller path, bolted down on the top surface of the seat, is 33 feet, Fig. 42, Plate 118, and its weight 12 tons; in the live-roller ring there are seventy-five cast-steel rollers, of a maximum diameter of 14 inches, weighing in all 10½ tons.

The framing is 27 feet in height, and weighs 50 tons. The boiler is 14 feet high by 6 feet diameter, and weighs 6 tons. The jib is composed of two tubes, each 3 feet 3 inches diameter at the centre, well braced together. It is 90 feet long, and weighs 45 tons, including stays; its extreme height above cope level of quay is 110 feet. The centre of the jib-head pulleys for heavy loads, which are 5 feet 3 inches diameter, is 100 feet above cope level of quay wall; and the light-load pulleys of 2 feet 6 inches diameter are 107 feet 6 inches above cope level. The single tension-rods are 10 inches by $2\frac{3}{4}$ inches, and the double tension-rods 10 inches by $1\frac{1}{2}$ inch, and the diameter of the pins 8 inches, the whole weighing 15 tons. The diameter of the hoisting drum is 5 feet 2 inches, its length 10 feet, and its weight $10\frac{1}{2}$ tons. The gearing weighs 8 tons; the castings are in all 120 tons; and the crane in working order, exclusive of back balance, is 270 tons. In the ballast box for balancing are 100 tons of iron and steel punchings.

The margins allowed for safety in the various parts of the crane are:—in the main framing, jib, tension rods &c., six to one; in the wire ropes, eight to one; and in the centre holding-down bolts, in order to provide amply for deterioration by rust, twelve to one. The crane has two speeds for heavy lifts, 130 and 60 tons and an empty block lift; and two for light lifts, 20 and 8 tons. The engine for the heavy lifts has two cylinders, each 12 inches diameter and 16 inches stroke; the engine for light lifts has two cylinders, each 8 inches diameter and 12 inches stroke. There are two speeds for revolving, and the turning engine has two cylinders, each 8 inches diameter and 12 inches stroke. Plough steel-wire ropes, made by Messrs. Thomas and William Smith, Newcastle, are used for lifting and lowering. The heavy lifts are taken on eight ropes of $2\frac{1}{8}$ inches diameter, composed of six strands of steel round one strand of manilla; each strand is composed of thirty-seven wires, 0·101 inch diameter, and the average tensile strength per wire is 1,600 lbs. The light lifts are taken on a double rope of $1\frac{1}{2}$ inch diameter, composed of six strands, each of thirty-seven wires of 0·072 inch diameter, round one centre strand of manilla; the average tensile strength per wire is 1,080 lbs. The gin block for heavy lifts has four pulleys, each 5 feet 3 inches diameter; it measures 12 feet by 7 feet by 3 feet, and weighs about 7 tons. The radius of sweep for the heavy lifts is 65 feet, or 45 feet beyond the face of the seat; and for the light lifts 71 feet, or 51 feet beyond face of seat.

The lifting speed for 130 tons is 4 feet per minute, 60 tons 8 feet, 20 tons 12 feet, 8 tons 30 feet, and empty block 32 feet per minute. The revolving speed with 130 tons is one revolution in five minutes; and with 60 tons and under, one revolution in two and a half minutes. To prevent the possibility of overloading at any time, the crane is provided with a Duckham's 160-ton hydrostatic weighing machine.

This crane was constructed and erected by Messrs. Cowans, Sheldon and Co., Carlisle, and is practically a duplicate of a crane made and erected by them on Finnieston Quay in 1893.

Throughout the harbour and docks berths are set aside for special trades, such as coal, lime, timber, river passenger steamers, and cattle; and more than half the total quayage of seven miles is occupied by the leading lines of steamers trading to outports of Scotland, England, and Ireland, to the leading ports of Europe, to the British Colonies, and to America, Canada, the East and West Indies, Africa, &c.

The riverside and dock quays are well equipped with everything necessary for the speedy loading and unloading of vessels, including $6\frac{1}{2}$ miles of harbour railway on each side of the harbour, connecting with the public railways. The Clyde Trustees have no warehouses, but have nearly 33 acres of floor space in sheds for the accommodation and protection of goods. The sheds most recently erected are those in Cessnock Dock; they cover 22,607 square yards of quay, and are two storeys high, equipped with apparatus for lowering general cargo into carts and railway wagons at the back outside, and with shoots for loading bags of flour into carts inside. Unlike dock companies, the Trustees do not load and unload goods; this work with its attendant profits is left to the shipowners to perform. Those who have allocated berths are allowed to place steam cranes on the breasts of the quays; and there are at present thirty-two of these in use, ranging from

2 P

30 cwts. to 30 tons lifting power. By means of fifty-five steam and hydraulic cranes, ranging from 30 cwts. to 130 tons lifting power, the Trustees load coals and heavy machinery, discharge ore, mast vessels, and place boilers and engines on board steamers built on the river banks and in the neighbourhood; and their four most powerful cranes rest on concrete cylinders similar to those described for the quay walls.

Graving Docks.—The first public graving dock in Glasgow harbour was opened in 1875, and is 555 feet long, with 22 feet 10 inches on the sill at high water of spring tides; it was constructed by the Clyde Trustees at a cost of £134,800, exclusive of land. A second, opened in 1886, 575 feet long by 52 feet 4 inches wide at bottom and 92 feet wide at top, with the same depth of water on the sill, was constructed alongside the first, by the author and from his designs, without the aid of contractors, as has been the case with all the quayage of the harbour for the last twelve years; the cost was £108,200, exclusive of land. A detailed description of this graving dock is given in appendix 2, pages 429–34. A dock of similar construction as regards material is now being built administratively like Cessnock Dock and under the same staff, alongside the second dock; its dimensions are 880 feet length, 81 feet 8 inches width at bottom and 115 feet at top, with 26 feet 6 inches depth on sill at high water of spring tides.

Ferries.—Ten cross-harbour passenger ferry-steamers provide an ample day and night service for four ferries within the limits of the harbour and two ferries at Govan and Whiteinch; while two vehicular and passenger ferries combined—at Finnieston, about the centre of the harbour, and at Govan, its western boundary—afford every facility for cart and carriage traffic.

The vehicular ferry steamer at Finnieston, designed and built by Messrs. William Simons and Co., Renfrew, commenced plying five years ago. Its novel feature is an elevating deck, raised and lowered by bevel and worm gearing, so that at any state of the tide the deck is brought to the same level as the quay. The hull is built of steel, with iron decking divided by thirteen bulkheads, five of which are transverse; it is 80 feet long by 44 feet broad, and 12 feet deep amidships, while the maximum draft when loaded is $9\frac{1}{2}$ feet. The vessel is propelled by four screws, two at each end, in order to give it great manœuvring power.

The elevating deck is 78 feet long by 32 feet broad; 19 feet of the width is for vehicles, and $6\frac{1}{2}$ feet on each side for passengers. It is carried, lifted, and lowered by three vertical screws on each side, of forged steel 7 inches diameter; these are supported by six columns formed of two box-girders, 12 by 14 inches, of channel section, which are placed 2 feet apart, one on each side of each screw. Each of the screws works in a manganese-bronze casing, which is bolted between the two box-girders that form each column, and is placed so that the deck may rise 14 feet. The columns are held in position at top by longitudinal and transverse steel girders of I section, and by girders of the same section fixed to the sides of the vessel; and on the top longitudinal and transverse girders is placed the wheelhouse, with handwheel to the steam steering gear on deck. The engines for propelling the vessel and for working the elevating deck are three horizontal triple-expansion, all of the same design and size, having cylinders 9 and $14\frac{1}{2}$ and 24 inches diameter with 18 inches stroke. All three are placed in one compartment in the centre of the hull. Two are placed athwartship, one of them driving the line of shafting that runs fore and aft and works the port screws at both ends of vessel, while the other drives the shafting for the starboard screws. The third engine is placed between the other two, with pistons working fore and aft, driving a line of shafting which runs athwartship, and is connected by spur and bevel wheels with two lines of fore and aft shafting on either side of the vessel; these are geared to each of the vertical screws for moving the elevating deck.

The vessel accommodates three hundred passengers and eight loaded carts with horses; or seven hundred passengers alone. It plies across the river between a recess on the north side and two dolphins on the south side; and has proved a perfect success in every way.

The Trustees have also a row-boat passenger ferry across the mouth of the Kelvin at its junction with the Clyde at Govan Ferry. The Renfrew Burgh authorities maintain a steam vehicular ferry across the river at Renfrew, and Lord Blantyre one at Erskine. The number of passengers conveyed across the river at the different ferries belonging to the Trustees for the year ending 30th June 1894 was 8,849,220, and of vehicles 233,167; and the gross revenue derived therefrom amounted to £18,735 3*s.* 4*d.* The charge for crossing is one halfpenny for each passenger; but eighteen single-journey tickets are sold for sixpence.

In April 1884 the Clyde Trustees established a service of harbour passenger steamers, each called "Clutha"—the Gaelic name of the Clyde—to ply between Victoria Bridge, Glasgow, and Whiteinch, a distance of 3½ miles. These steamers, now ten in number, are twin-screw, 74 to 102 feet long by 13 to 17 feet beam, carrying from 235 to 360 passengers. They ply at ten minutes' intervals, at the fare of one penny for the whole distance; and call at various intermediate stations on both sides of the harbour. During the year ending 30th June 1894 they carried 3,376,425 passengers with a gross revenue of £14,068 8*s.* 9*d.*

APPENDIX 1.

NEW DREDGING PLANT.

The new Dredging Plant consists of a single-ladder twin-screw dredger, 200 feet long by 37 feet broad by 12½ feet deep, having a mean draft of 8 feet, capable of dredging at the rate of 600 tons per hour in 40 feet depth of water, and of cutting its own flotation; and two twin-screw hopper-barges of 1,000 tons capacity, each 200 feet in length by 34 feet in breadth moulded, and 15½ feet deep, having a speed of ten knots per hour when loaded, and a mean draft of 12½ feet. All three vessels were constructed in 1892 by Messrs. Fleming and Ferguson, Paisley, from drawings and specifications prepared by the author. The plating of the hulls of both dredger and barges is of steel; and steel has been used wherever it could with advantage be applied.

Dredger.—Plates 102 and 103. The hull is subdivided into eight water-tight compartments by means of iron bulkheads. The decks are of pitch pine. Steam and hand steering gear are provided. The dredging and propelling are performed, the latter at a maximum speed of 6 miles per hour, by a pair of compound inverted direct-acting surface-condensing engines, capable of indicating 750 horse-power with a working pressure of 80 lbs. per square inch above atmosphere; the cylinders are 26 inches and 51 inches diameter, with a stroke of 36 inches. The propellers are of steel; and are protected by strong iron guards, supported and stayed from the vessel's counter. The boilers, two in number, each have two furnaces, 3 feet 3 inches diameter, giving a heating surface collectively of fully 2,000 square feet; they are multitubular, 10 feet long by 11 feet 8 inches diameter, of mild steel, and according to Board of Trade requirements; the water is heated before admission by a Rayner feed-water heater.

The main framing for carrying the upper tumbler, ladder, and traversing gear, is of iron plating, of box form with outside angles and of ample strength, securely connected to the hull by specially prepared seating, and by brackets to the sides of the well and to the keelsons. The sheers for carrying the lower end of the bucket ladder are also of box form, well trussed in the direction on the strain, and firmly secured to keelsons, deck-beams, &c. The upper and lower tumblers are of cast-steel; the upper is five-sided and the lower seven-sided. The buckets, thirty-five in number, each of 22 cubic feet capacity, are constructed entirely of steel, with hard steel wearing-plates. The intermediate links and link pins are of best forged scrap-iron; the pins are steeled on the working side and hardened. The bucket ladder is built in the best style of girder work, with all butts and edges of plates planed; it is formed of two parallel plate-girders, bound together at top and bottom by cross ties of box section, with eleven intermediate plate-ties. There are two shoots on each side of the dredger for loading barges, placed to suit the forward and aft positions of the bucket ladder; all four shoots are worked by a pair of horizontal engines in a house on the deck. The traversing carriage on the main framing is worked by an independent vertical engine and gearing; it travels sufficiently far aft, which will be its usual position in working, to admit of the ladder and lower tumbler, with all the buckets in position, being hoisted on deck for inspection and repairs.

All spur and bevel pinions and mitre wheels in connection with the main and hoisting gearing are of cast-steel, while the large wheels are made of a special mixture of cast-iron and steel. The dredging machinery is adapted by steel change-wheels to drive the buckets at speeds of 12 and 18 per minute without altering the speed of the engines from 60 revolutions; while by varying the speed of the engines any intermediate speed of buckets between 12 and 20 per minute can be obtained, when dredging to a depth of 40 feet below the surface of the water, with the ladder set at an angle of 45 degrees. Provision is made by adjustable friction-gear, fitted to the top-tumbler wheel, to relieve the machinery of any sudden strain which might otherwise be brought upon it by the buckets meeting with obstructions, such as boulders, sunken wrecks, lost anchors, &c. Powerful steam mooring winches are fitted, two at the bow and one at the stern. The maximum speed of the former is 50 feet per minute in working ahead on the bow-anchor chains; and the maximum speed for side chains or ropes is 60 feet per minute The maximum speed of the stern winch, for taking in anchor chains, is 90 feet per minute; and the maximum speed for side chains or ropes is 120 feet per minute. The backing speed in both bow and stern winches is 90 feet per minute. The hoisting of the bucket ladder, which can be done at any speed up to 13 feet per minute, is performed by a pair of horizontal engines, with 14-inch cylinders and 16 inches stroke; and the lowering is done by a powerful brake handled on the deck. The hoisting purchase consists of four upper and five lower brass-bushed wrought-iron sheave-blocks. The hoisting chains are $1\frac{3}{8}$-inch diameter, of crane-chain quality, short linked, tested to Admiralty strain, and wound on a spiral-grooved cast-iron barrel, 10 feet long and 7 feet diameter, large enough to take the whole chain on it without riding. A 10-ton steam derrick crane is placed on deck, so as to command the bottom tumbler, and to place it on a barge or punt, or on a quay. The dredger is lighted throughout by electricity, with incandescent lights on deck and below, and three arc-lights of 2,000 candle-power each; the latter are suspended in triangular form 6 feet apart, from an iron post with a cross-tree, placed on the top of the main framing, in compliance with the rule for the lighting of dredgers moored in the harbour of Glasgow and in the river Clyde.

Barges.—As shown in Plate 104, the barges have each a raised fore-castle, a main steering bridge and wheel house, a flying steering bridge, and a gangway extending from the fore end of the hopper to the main bridge. The hulls of each are subdivided into six water-tight compartments by bulkheads carried up to the main deck; and there is a water-ballast space on each side of the length of the hopper, 8 feet high from the bottom plating, with a water-tight deck, each space being divided into two compartments by a transverse bulkhead, with pipe connections for filling and emptying each of the four compartments.

The hopper is 72 feet long by 27 feet wide at deck line, and 11 feet wide at bottom, with a depth of 15 feet to deck line. It is divided into two equal compartments by a partial bulkhead, carried up to support the curved box-girder in which are fixed the pulleys for working the hopper-door chains. The hopper doors are of elm, twelve in number, hinged to the bottom of the hopper sides, and closing against a fore-and-aft box-keelson, $3\frac{1}{2}$ feet high by 2 feet wide. For protecting the hopper sides against damage by stones falling heavily upon them, $\frac{3}{8}$-inch malleable-iron plates, 4 feet wide, are hung from the deck beams along both sides of the hopper.

The barges are each propelled by two triple-expansion engines of 1,200 I.H.P. collectively, each driving its own propeller; the cylinders are 15 and 24 and 37 inches diameter, with a stroke of 24 inches. Each engine is fitted with independent steam starting-gear, so that one man can handle both engines with ease. Steam is supplied at 150 lbs. per square inch by two return multitubular boilers, each 12 feet diameter by 10 feet long, with Purves' corrugated furnaces 3 feet 6 inches diameter; the water is heated before admission to the boilers, as in the dredger. The propellers are 9 feet diameter, having four steel blades bolted on; and the shafting is 8 inches diameter. The vessels are steered by Messrs. Alley and MacLellan's steam steering-apparatus, which can be worked from either of the bridges. In the wheel house is one of Sir William Thomson's compasses, and on the flying bridge an ordinary compass. Messrs. France and Morgan's reply telegraphs are fitted on both bridges, communicating with each engine in the engine-room.

There are two sets of powerful three-barrelled winches on deck, one set immediately forward and the other immediately aft of the hopper, for manipulating the hopper doors; each set is worked by a two-cylinder horizontal engine, while they are so designed as also to be worked by hand. One of Messrs. Clarke, Chapman and Co.'s steam windlasses is fitted on the fore-castle for working the anchor chain and mooring ropes; and a steam capstan by Messrs. Alley and MacLellan is placed at the stern for mooring.

APPENDIX 2.

No. 2 Graving Dock.

The following are the principal dimensions of this dock, which was opened on 13th October 1886 :—

	Feet.	Ins.
Length of floor from inside of caisson . .	575	0
Width at bottom	52	4
Width at top	92	0
Width of entrance at bottom . . .	57	6
Width of entrance at top	67	0
Depth of water on centre of sill at average high water of ordinary spring tides .	22	10

The wing walls and apron of the entrance are carried on triple concrete cylinders 9 feet diameter outside and 5 feet 9 inches inside, sunk 24 feet into the ground, and filled with concrete, their tops being 3 feet below the level of top of sill at centre. One of the triple cylinders was used as a well for the main temporary 13-inch centrifugal pump by Messrs. Easton and Anderson, which was required to keep under the heavy influx of water that was met with in the gravel into which the excavation for the dock had to be carried. Into this well were led three lines of 9-inch open-jointed spigot-and-faucet pipes, made of cast-iron under the sills, and of fire-clay thence to the upper end of the dock. These pipes were laid under the foundations of the floor on an inclination of about 1 in 300, with branches to each side as required, in order to give free passage to every spring of water that was met with. In order to prevent these lines of pipes from choking with sand, a small wire-rope with wire brush attached was carried through each from the well right on to the upper end, as the work of excavation proceeded from the entrance to the head of dock; these brushes were quite successful in keeping the pipes clear. The pipes were bedded in clean riddled gravel to the depth of 18 inches, whereby the ground was kept well dried for laying the bottom bed of concrete forming the lowest section of the foundations of the floor and side walls. On this concrete bed, which is 12 inches thick at the centre and 3 feet 2 inches at the sides, an invert of brick in cement, 4 feet 2 inches thick, was laid to the radius of 120 feet, surmounted by a bed of concrete 4 feet 5 inches thick in the centre, tailing out to 12 inches on each side, with a camber of 6 inches on the upper surface. On this is laid the flooring of the dock, consisting of nidged granite causeway 6 inches thick, set in and grouted with cement. The floor at the centre is 12 inches below the sill, and is level longitudinally.

The limited width of the site of the dock prevented the excavation from being taken out to the usual width on the top. This, with the desire to get the dock as long as the ground would admit of, necessitated driving along both sides and round the head pitch-pine sheet-piling 28 feet long, in four-pile bays with slip tongues; 16 feet of the length was driven into the undisturbed bottom, and the piling is 9 inches thick along the sides, and 12 inches thick round the head. In front of the sheet-piling, brickwork was carried up from the invert to above the top of the piling; and the ground behind the piling was cut away for a breadth of 7 feet 6 inches and a depth of 6 feet, and filled up with concrete, on which were built the outer side walls, 37 inches thick at bottom and 18 inches at top, plumb at back and stepped on the inside, the whole being carefully pointed outside to secure water-tightness. Inside the walls the whole body of the dock is of concrete, except the side walls of the entrance, the stairs, timber slides, top altar course, and cope, which are of granite; all the other altar courses, seventeen in number, are of granolithic, 14 inches on the tread and 18½ inches rise, except the bottom course, which has 30 inches average rise. The concrete of the sides was put in between movable frames roughly stepped to receive the granolithic altar courses, which were moulded on a platform on the working ground, and when thoroughly dry were built in position like ashlar: except the bottom altar course, which was made *in sitû* in 8 feet lengths and in alternate blocks, to allow of setting and shrinkage.

The floor of the caisson chamber is an invert of brick in cement, with granite stones and cast-iron blocks alternately for carrying the rails for the caisson to travel on, the cast-iron blocks being cored out for the drainage of the mud from the rails. The sides and end walls of the chamber are of brick, with rectangular voids filled with concrete, and having a freestone string-course on each side for the hauling-chain path. The caisson chamber is covered over with Lindsay's steel-trough decking, having the troughs filled up with concrete and a layer 4 inches thick over the whole, which is causewayed over to form a part of the roadway.

The semicircular head of the dock is formed of brick in cement, stepped at back, with rectangular voids filled with concrete, and faced with moulded granolithic-faced concrete ashlar, battered on the face to 1 inch per foot in courses of 18 inches deep, chamfered on top and bottom edges; the stretchers are 4 feet long by 1 foot 9 inches broad on bed, and the headers 3 feet 6 inches long by 2 feet broad. On each side of the dock there are four timber slides, and two stairs, with two stair approaches to each. The stairs are 4 feet 6 inches wide, with landings about half way down. Each landing is approached from the surface by two stairs parallel with the dock, and entering from opposite directions; the steps of the stairs are 12 inches broad and 6½ inches rise.

The caisson for closing the entrance is of iron, rectangular in shape, as first used in 1850 to close the lock entrance at Keyham, with folding roadway, and handrails, similar to the caisson with folding handrails and lowering and raising roadway deck, which was adopted in 1867 by Sir Andrew Clarke to close the entrance to the Royal Somerset graving dock, Malta; but instead of sliding, as at Malta, it is moved on rollers fixed under it, which run upon broad iron rails, laid on each side of the floor of the chamber and berth, as successfully applied by Mr. Kinipple in 1873 at Garvel graving dock, Greenock. The caisson has a water-tight deck about half way between bottom and top, and is ballasted with 180 tons of concrete ballast, 60 tons of which is portable, being in 12-inch cubes; these can be lifted out for enabling the caisson to be floated out of its recess if required.

The whole of the cement used in the construction of the dock was the best quality of Portland. The proportions of gravel and broken stones to cement for the concrete were as follows:—for the triple cylinders, 5 to 1; floor and sides of dock and ballasting of caisson, 6 to 1, the concrete on the sides being supplemented by a plentiful supply of rubble; covering of the caisson chamber, 8 to 1; and filling of the concrete cylinders, 9 to 1. The gravel for the concrete was mostly got from the excavations, and the remainder was Thames gravel brought round from London as ballast; a considerable quantity of the rubble stones were got from the blasting of Elderslie rock in the river above Renfrew. All the concrete was mixed by Jamieson's mixers, and the stones were broken by Hope's stone-breaker. The granolithic altars consist of three of crushed granite to one of cement; and the granolithic-faced ashlar blocks are faced with 6 inches of granolithic of the same quality, the remainder of the block being 5 to 1 concrete. The mortar for building the brickwork was composed of 1 of cement to $2\frac{1}{2}$ of sharp sand; and for pointing, 1 of cement to 1 of sand. All the sand was obtained from the excavations for the dock.

The dock is emptied by the pumping engines of No. 1 dock through a cast-iron pipe 5 feet 9 inches bore; but this pipe having been put in simultaneously with the construction of No. 1 dock when the second dock was intended to be 2 feet 10 inches less in depth than it actually is, the last few inches of water above the floor in No. 2 dock have to be emptied by a 10-inch auxiliary centrifugal pump by Messrs. Easton and Anderson, which is driven by a 16-H.P. gas engine by Messrs. Crossley Brothers, Manchester. The caisson was made by Messrs. Hanna, Donald and Wilson, Paisley; the caisson hydraulic hauling engine, which can also be worked by hand, is by Messrs. Tannett, Walker and Co., Leeds; and a new hydraulic pumping engine, for supplying the accumulator for the hydraulic power to work the hauling engine of No. 2 dock and the capstans and sluice valves of both docks, has been supplied by Messrs. Fullerton, Hodgart and Barclay, Paisley. The sluices were furnished by Messrs. Easton and Anderson. All the three engines are underground, in roomy white-glazed brick-lined houses, two of which are roofed over at the surface with rolled beams and concrete and Gourlay's prismatic lenses for lighting.

The strata which had to be excavated for the dock consisted of about equal proportions of soft clay, sand, and gravel. The excavations amounted to 188,943 cubic yards, of which—

148,167	cubic yards	were deposited in Loch Long.
11,505	,,	,, gravel used for concrete.
22,686	,,	,, sand sold.

There were built in the construction of the dock—

21,000	cubic yards of	concrete.
1,700	,, ,,	rubble concrete.
19,000	,, ,,	brickwork.
12,000	cubic feet of	freestone ashlar.
31,000	,, ,,	granite ashlar.
4,800	,, ,,	concrete ashlar.

3,000 square yards of granite-nidged causeway 6 inches thick.
16,000 linear feet or 3·03 miles of granolithic altar courses.

The act for the dock was passed on 7th July 1873. Ground was broken for its construction on 2nd August 1882. Pumping was commenced on 1st June 1883. The sinking of the first concrete cylinder was commenced on 21st December 1883. The concrete foundation of the dock entrance and caisson chamber was commenced on 26th May 1884, and the first brick was laid on 29th May. The last cope-stone was laid on 27th March 1886. The pumping ceased and the dock was ready for opening on 30th August 1886; the delay of the opening till 13th October was consequent on the removal of the cofferdam across the entrance, and the completion of the dredging of the entrance.

The number of men employed on the work varied from 100 to 300; no loss of life or limb occurred during the execution of the work. The plant employed consisted of:—one locomotive; two portable pumping engines; one 12-inch and one 13-inch centrifugal pump; one portable engine, working a stone breaker and a concrete mixer; one portable engine working a concrete mixer; two Jamieson's concrete mixers; one Hope's stone breaker; two 10-ton steam overhead travelling cranes; one hauling engine; one 10-ton, four 5-ton, and one 3-ton steam derrick cranes; three 3-ton hand derrick cranes; forty 3-yard wagons; 40-lbs. to 75-lbs. steel rails, &c.

The parliamentary plans were prepared and carried through parliament by the author, who also prepared the working drawings and constructed the dock without the aid of contractors.

The PRESIDENT said the author had given the Institution a paper on a large and important piece of work which he had most successfully carried out. Its interest was perhaps not so exciting as that of some recent papers on similar work which had caused much trouble by failures; but it was at least as instructive, and certainly much more pleasing to its author. In this paper Mr. Deas had done something which was always most acceptable to engineers: he had given a mass of details, both important and interesting, but seldom made public in regard to work of this kind. Although the paper was not discussed, he was sure the Members would join in giving Mr. Deas a most hearty vote of thanks for the elaborate and complete way in which he had placed before them the results of his long experience.

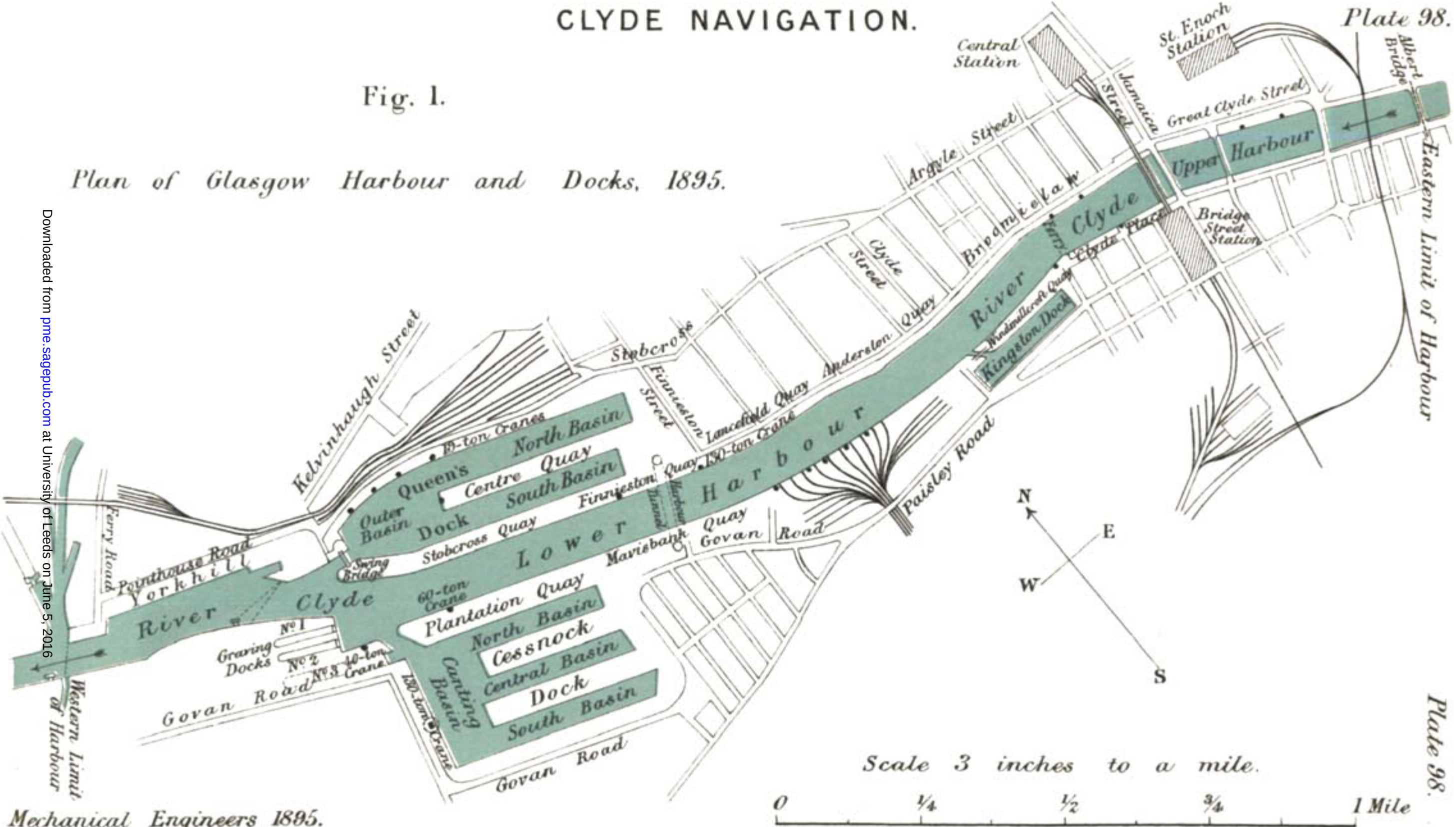
Mr. DEAS said he had not expected that the paper would lead to any discussion. Having been a mechanical engineer before he became a civil engineer, he realised how largely the work which had been carried out on the Clyde during the last twenty-five years had been indebted to mechanical engineers for the facilities they had afforded, especially in regard to the mode of sinking cylinders by the diggers, which had been so successfully applied not only to cylinder sinking on the Clyde but in other works of the same kind. The novelty connected with the works of the Queen's Dock and the Cessnock Dock was to a considerable extent due to the adoption of concrete cylinders instead of iron. Iron cylinders were much too costly for the substructure of quay walls; and his attention had therefore been directed first to brick cylinders, which were found successful. Afterwards he had decided to go a step further and use concrete, which had been equally successful. Upwards of three miles of the quay walls of Glasgow Harbour had been founded on concrete cylinders; and the maintenance of these since they were constructed had not cost the Clyde Trustees £100. Even in the brick walls not a brick had required to be put in for repairs.

CLYDE NAVIGATION.

Plate 98.

Fig. 1.

Plan of Glasgow Harbour and Docks, 1895.

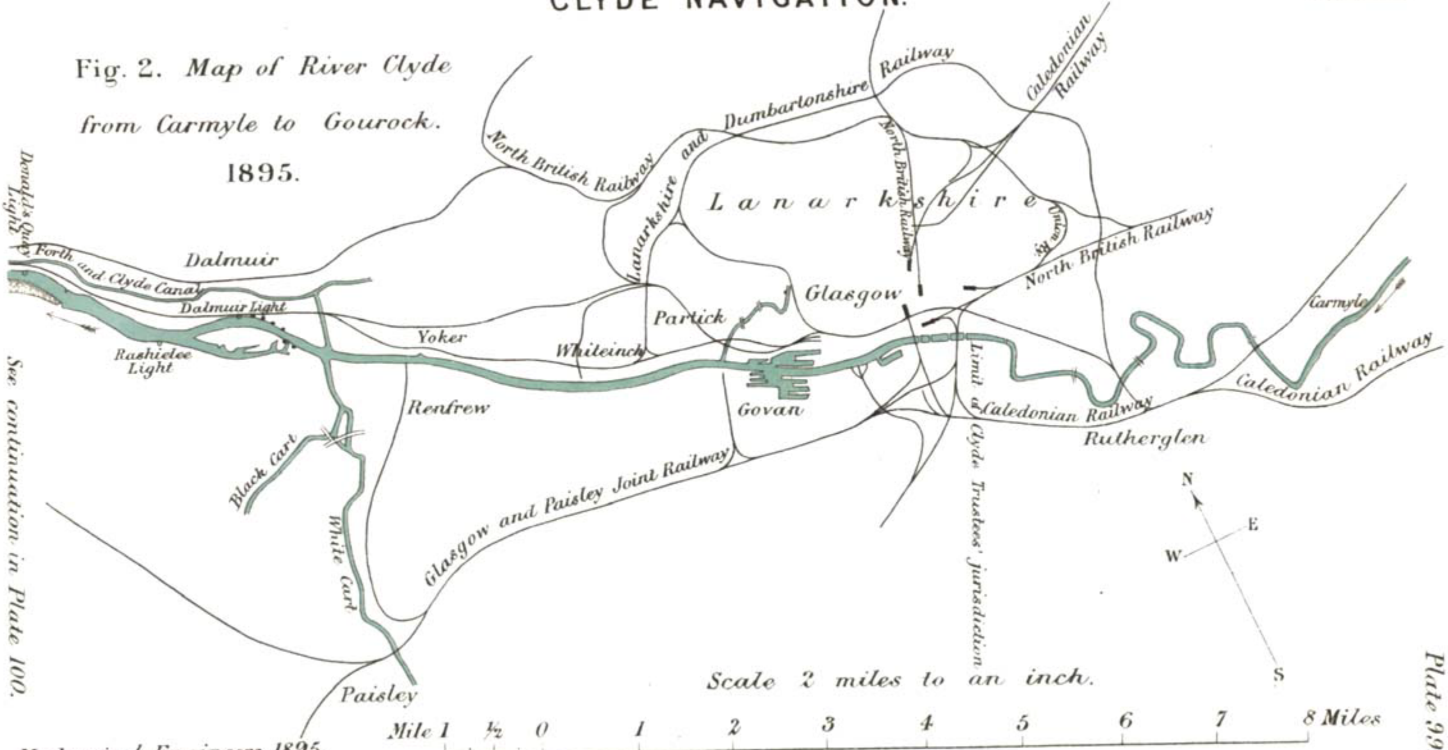


Scale 3 inches to a mile.

Plate 98.

CLYDE NAVIGATION.

Fig. 2. Map of River Clyde
from Carmyle to Gourock.
1895.



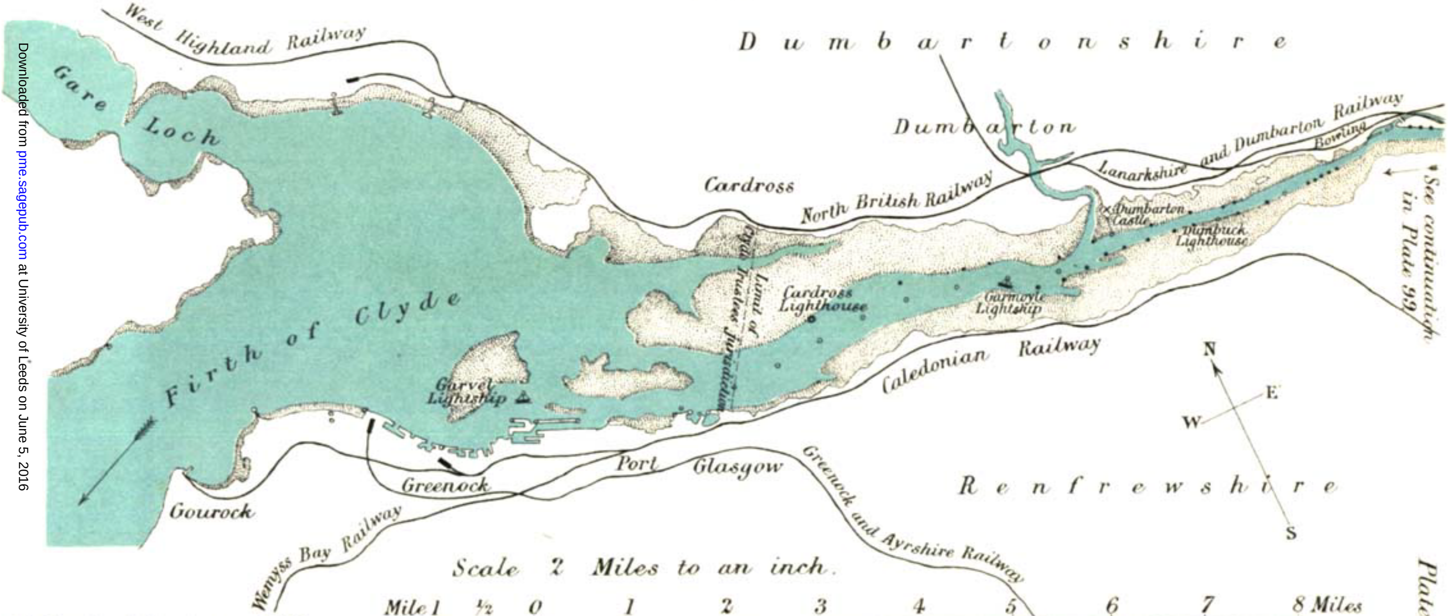
See continuation in Plate 100.

Plate 99.

CLYDE NAVIGATION.

Fig. 3. Map of River Clyde from Carmyle to Gourock.

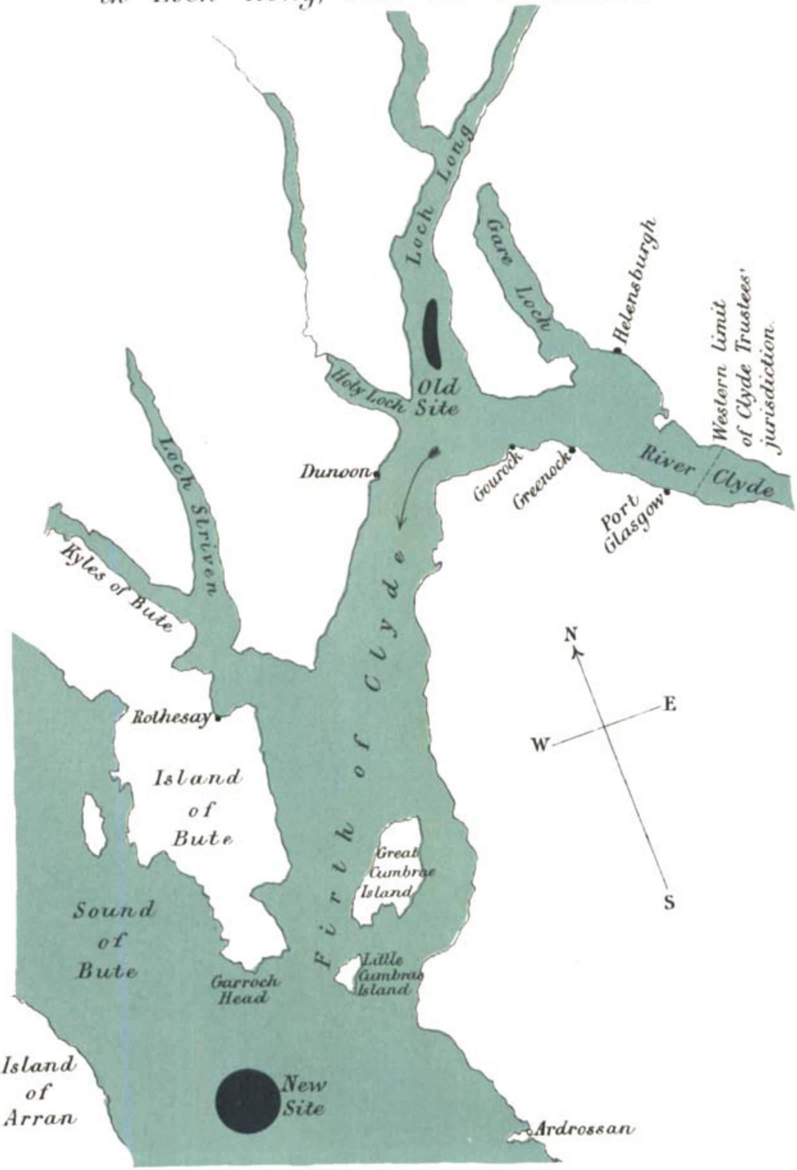
1895.



Mechanical Engineers 1895.

CLYDE NAVIGATION.

Fig. 4. *Plan of Firth of Clyde showing sites for Depositing Dredgings in Loch Long, and off Garroch Head.*



Mechanical Engineers 1895.

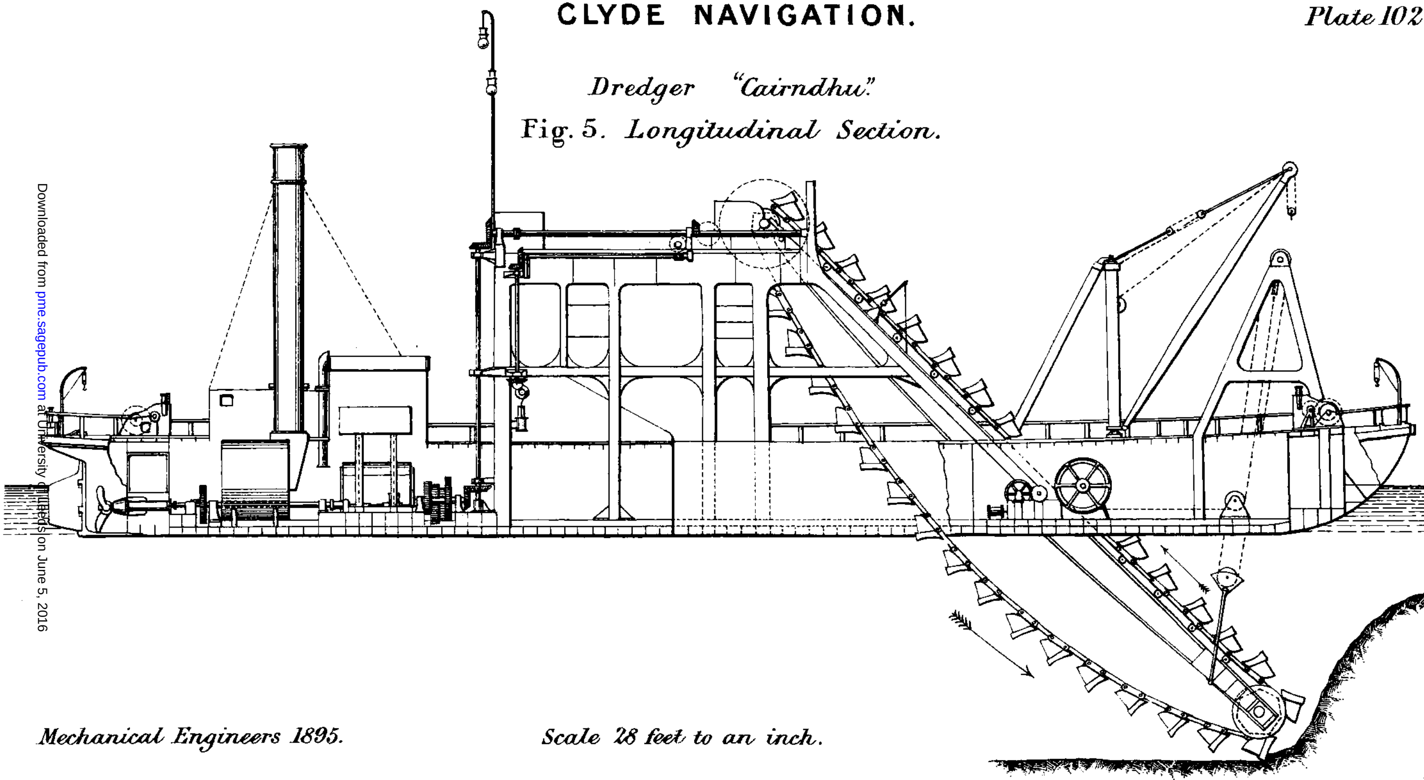
Scale 6 miles to an inch.

0 5 10 15 20 Miles

CLYDE NAVIGATION.

Dredger "Cairndhu."

Fig. 5. Longitudinal Section.



Mechanical Engineers 1895.

Scale 28 feet to an inch.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

CLYDE NAVIGATION.

Dredger "Cairndhu."

Fig. 6. Plan.

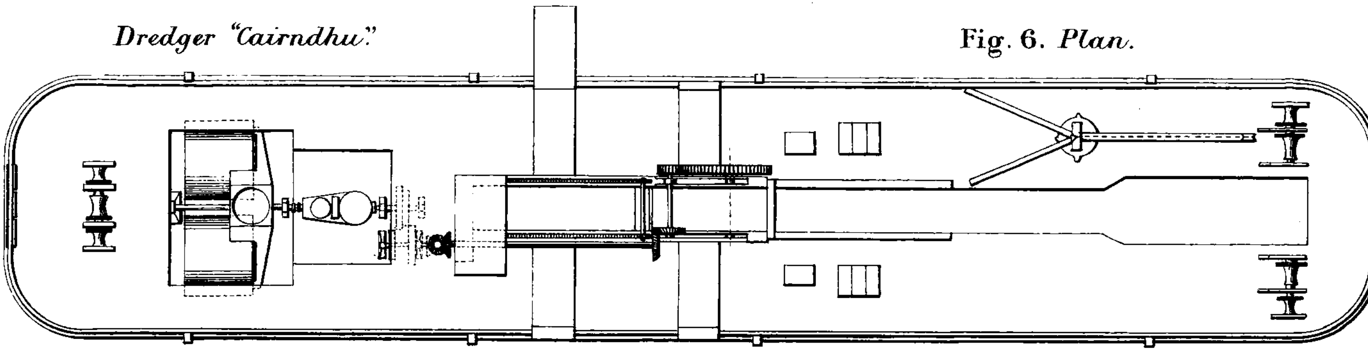


Fig. 7.
Transverse Section at Boilers.

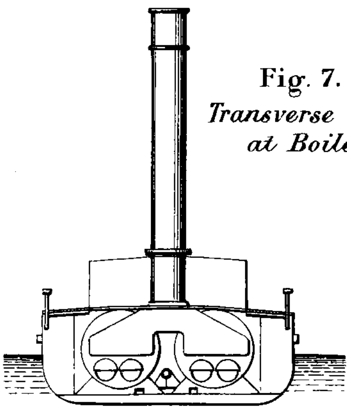


Fig. 8.
Transverse Section at Shoots.

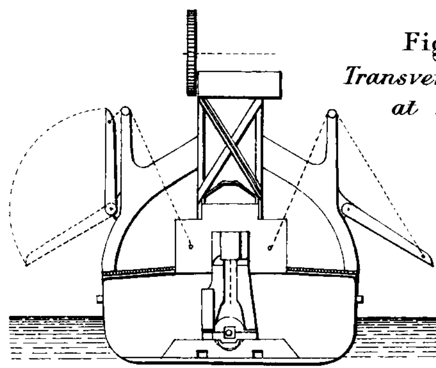


Fig. 9.
Transverse Section through Well.

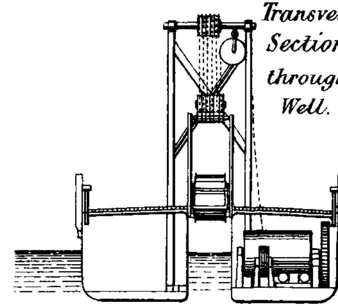


Plate 103.

Scale 28 feet to an inch.

CLYDE NAVIGATION.

Hopper Barges.
Nos. 1 and 3.

Scale 28 feet to an inch.

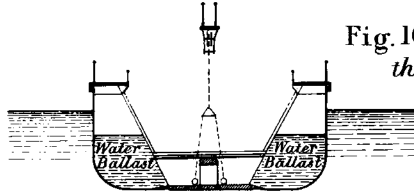


Fig. 10. *Transverse Section through hopper.*

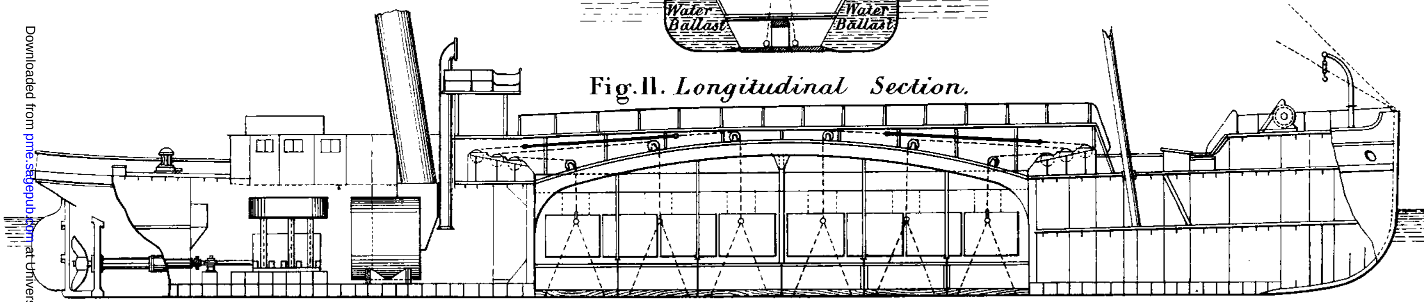


Fig. 11. *Longitudinal Section.*

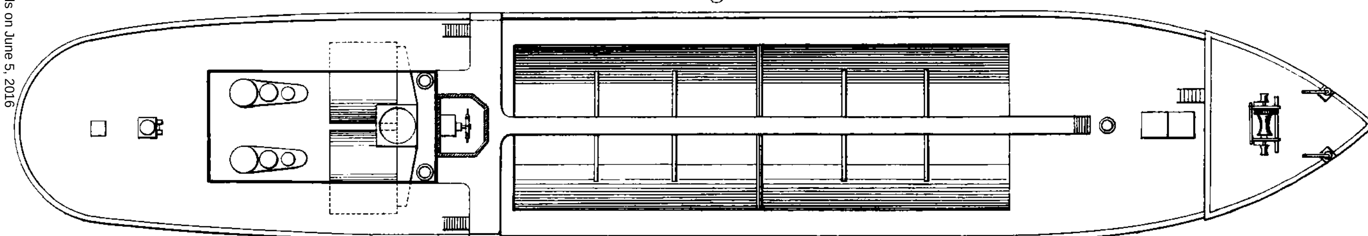


Fig. 12. *Plan.*

Plate 104.

Plantation Quay Wall.

Fig. 13. Section of first portion.

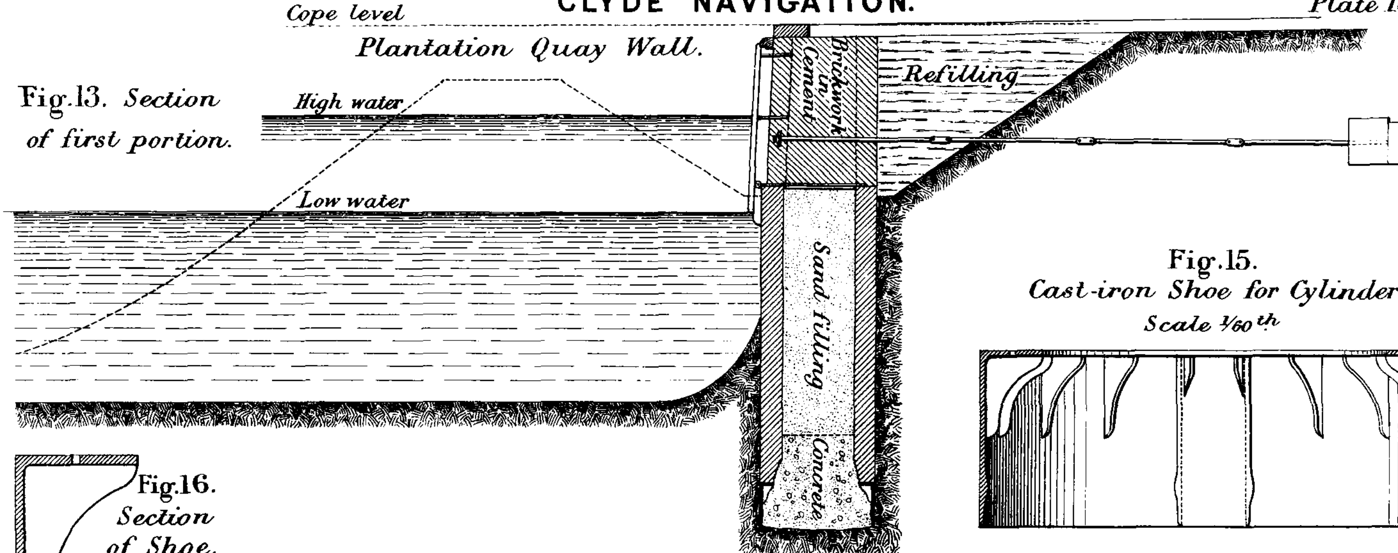


Fig. 15. Cast-iron Shoe for Cylinder. Scale 1/60th

Fig. 16. Section of Shoe. Scale 1/30th

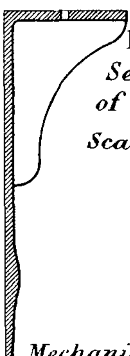
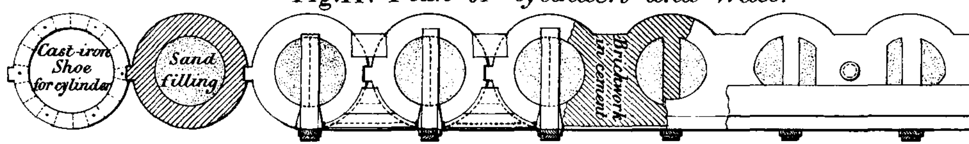


Fig. 14. Plan of Cylinders and Wall.



Scale 20 feet to an inch.

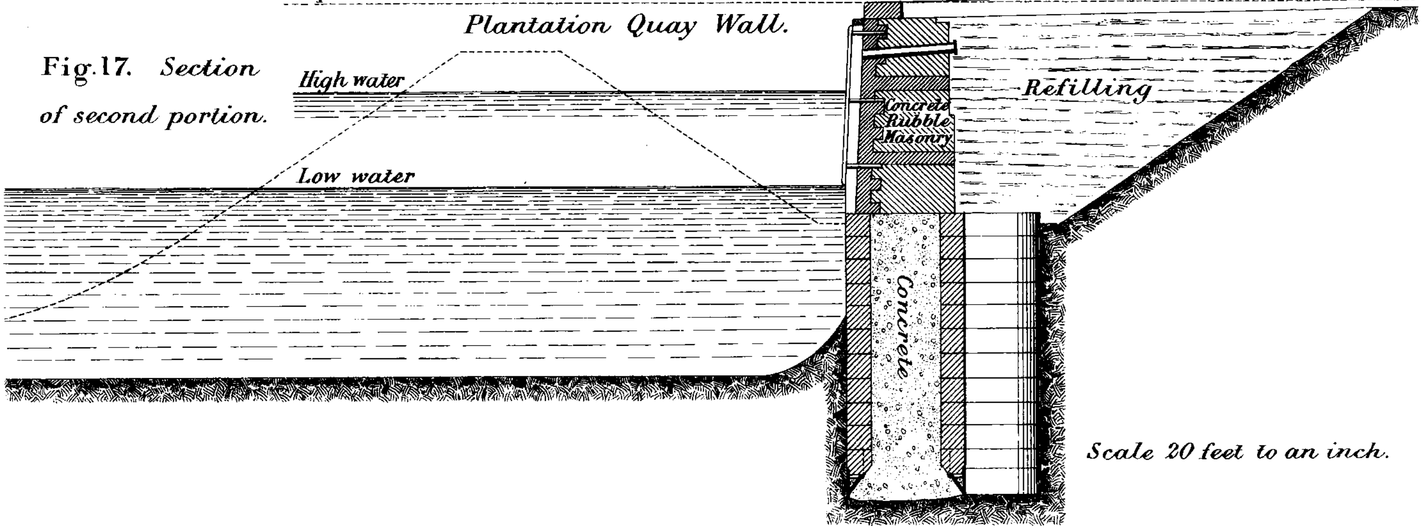
Feet 10 5 0 10 20 30 Feet

Plate 105.

CLYDE NAVIGATION.

Plantation Quay Wall.

Fig. 17. Section of second portion.



Scale 20 feet to an inch.

Fig. 18. Plan of Cylinders and Wall.

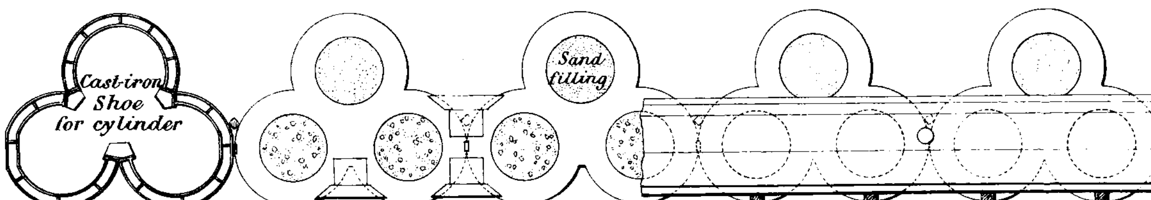


Plate 106.

CLYDE NAVIGATION.

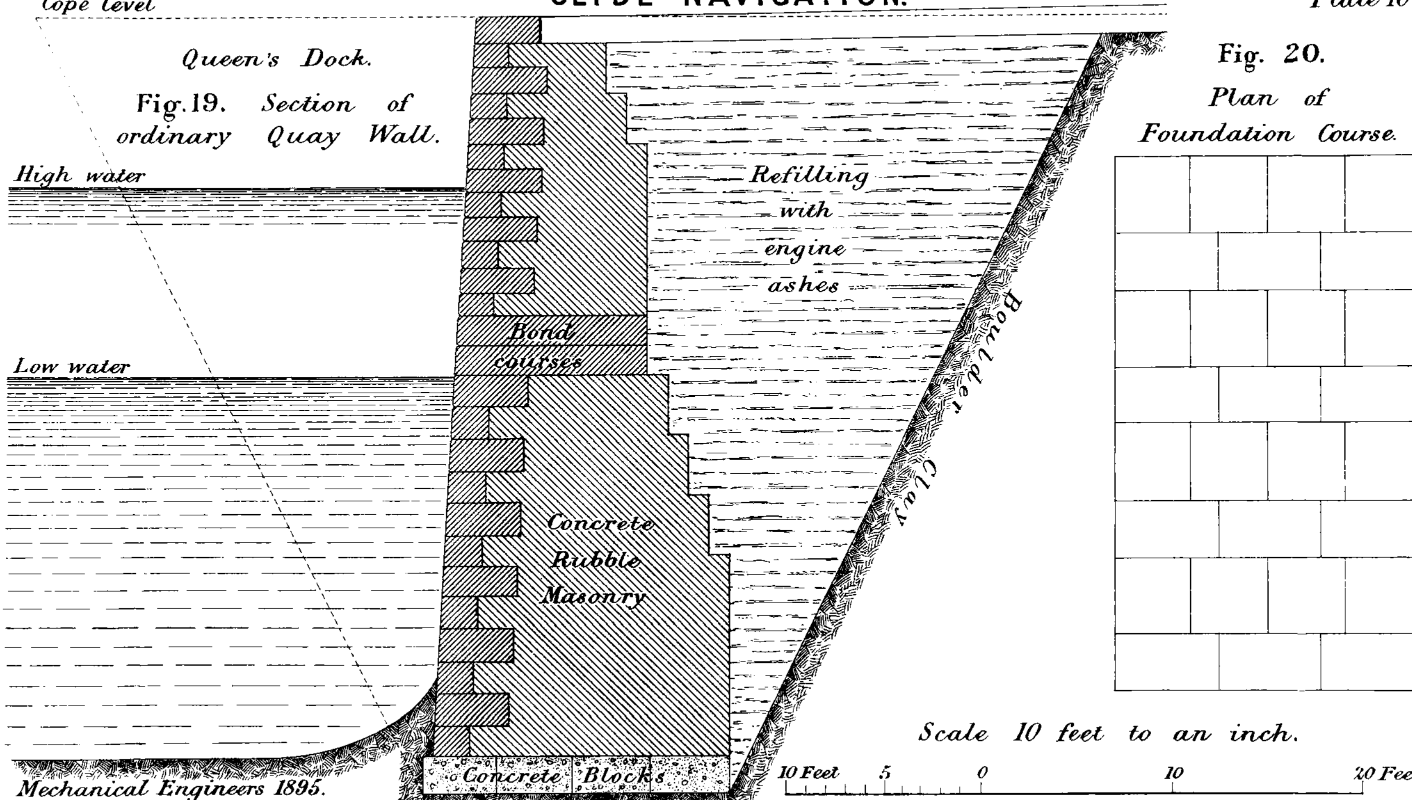


Plate 107.

CLYDE NAVIGATION.

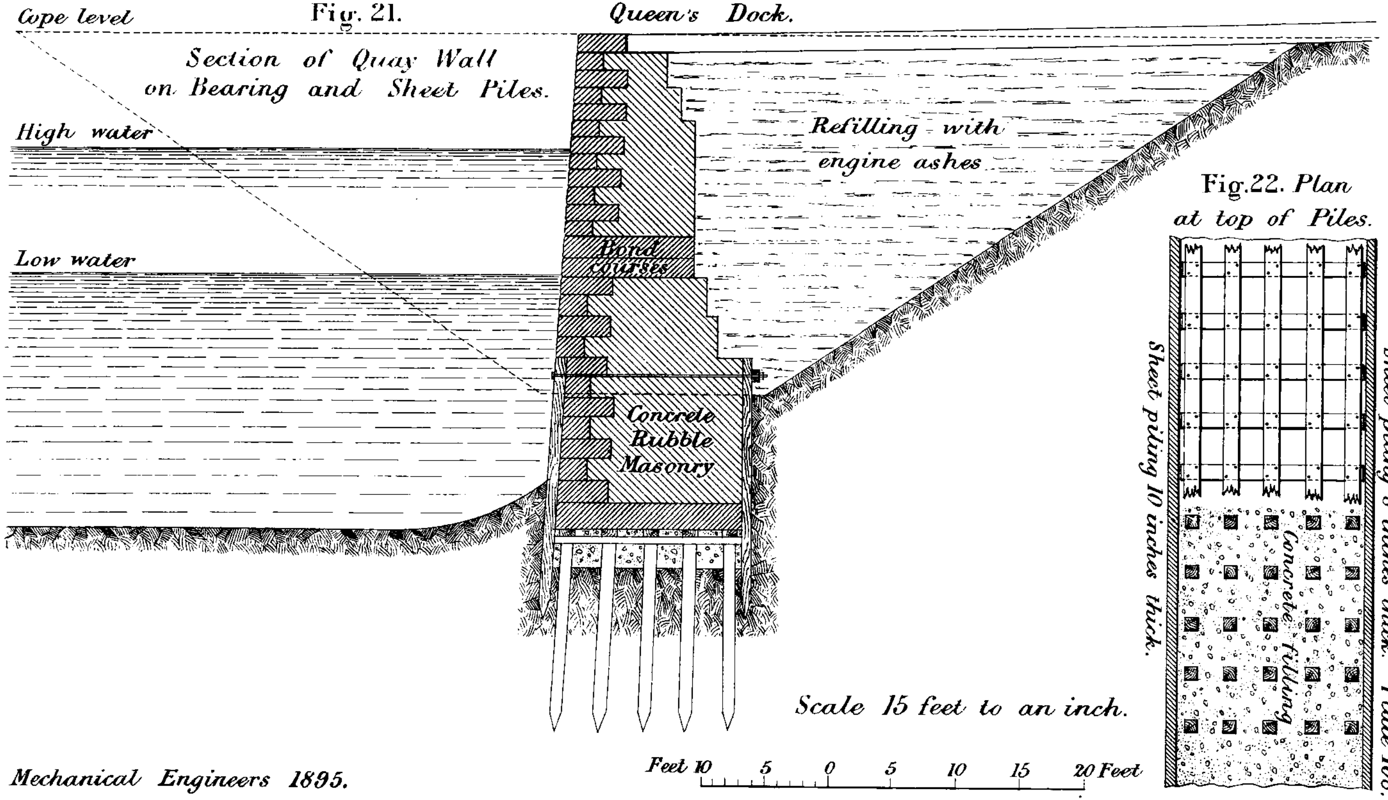
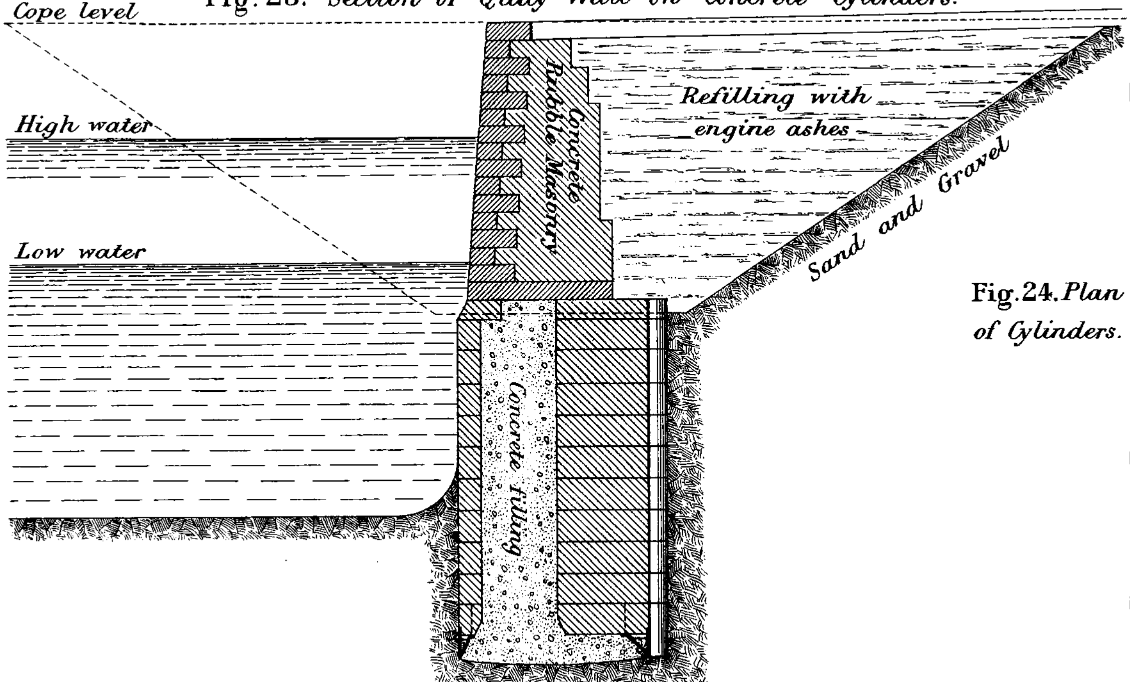


Plate 108.

CLYDE NAVIGATION.

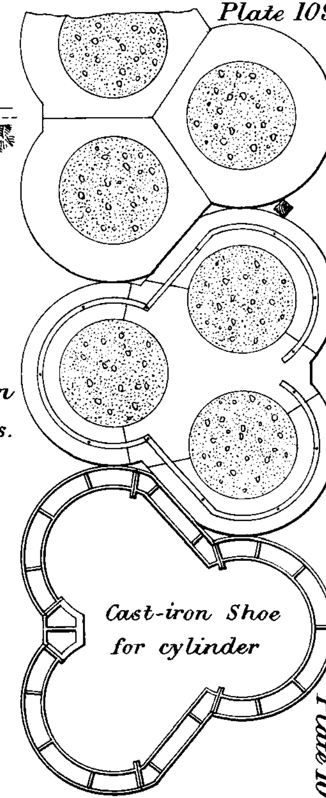
Queen's Dock.

Fig. 23. *Section of Quay Wall on Concrete Cylinders.*



Scale 15 feet to an inch.

Fig. 24. *Plan of Cylinders.*



Scale 10 feet to an inch.

Plate 109.

Plate 110.

CLYDE NAVIGATION.

Queen's Dock. Cast-iron Shoe for Cylinder.

Fig. 29. *Section at Joint J.*

Scale 1/8th.

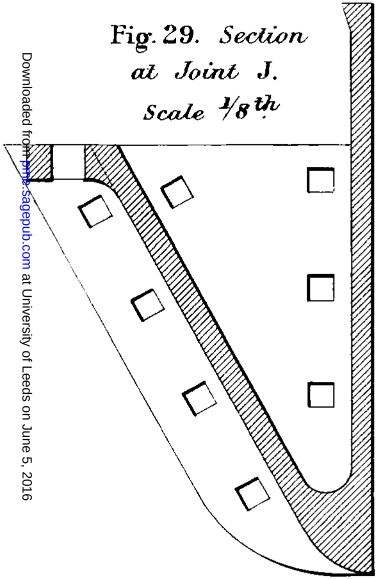


Fig. 26. *Section at* XX.

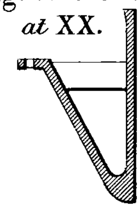


Fig. 27. *Section at* YY.

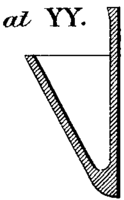
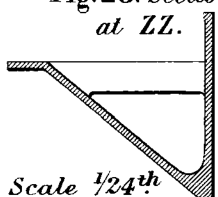
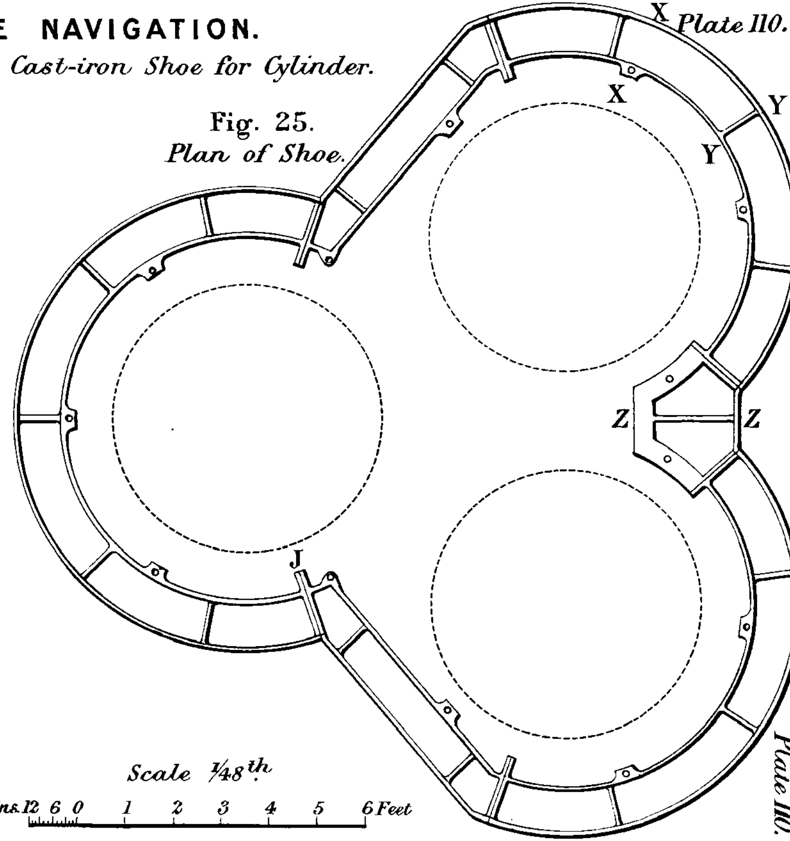


Fig. 28. *Section at* ZZ.



Scale 1/24th.

Fig. 25. *Plan of Shoe.*



Scale 1/48th.

Mechanical Engineers 1895.

Plate 110.

CLYDE NAVIGATION.

Plate III.

Queen's Dock.

Fig. 30. *Section of Wharf.*

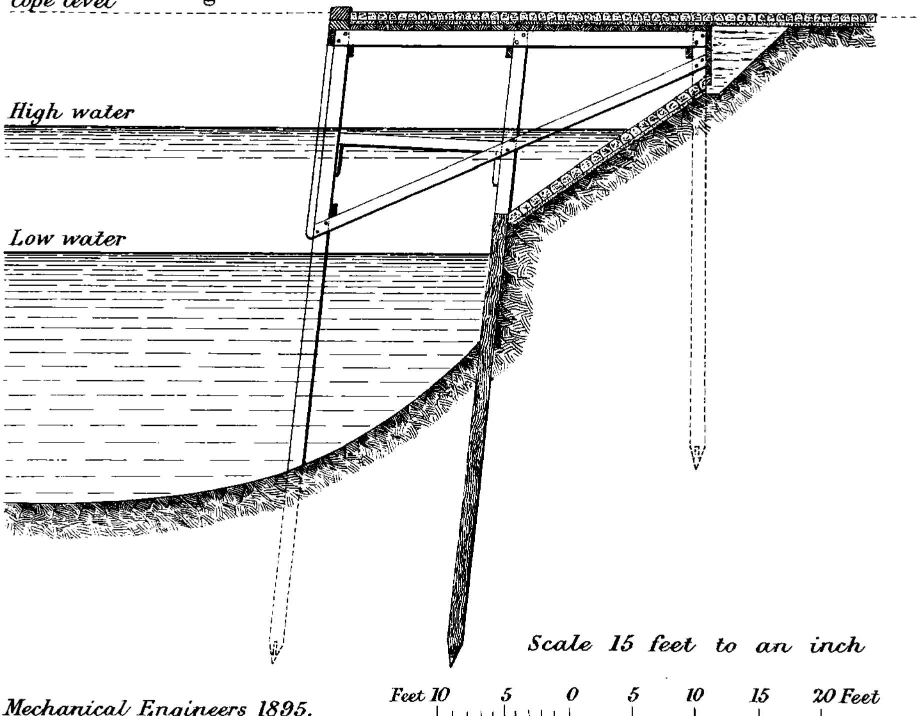
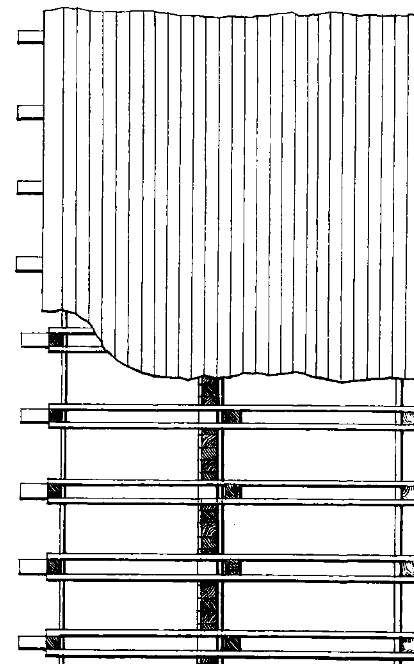


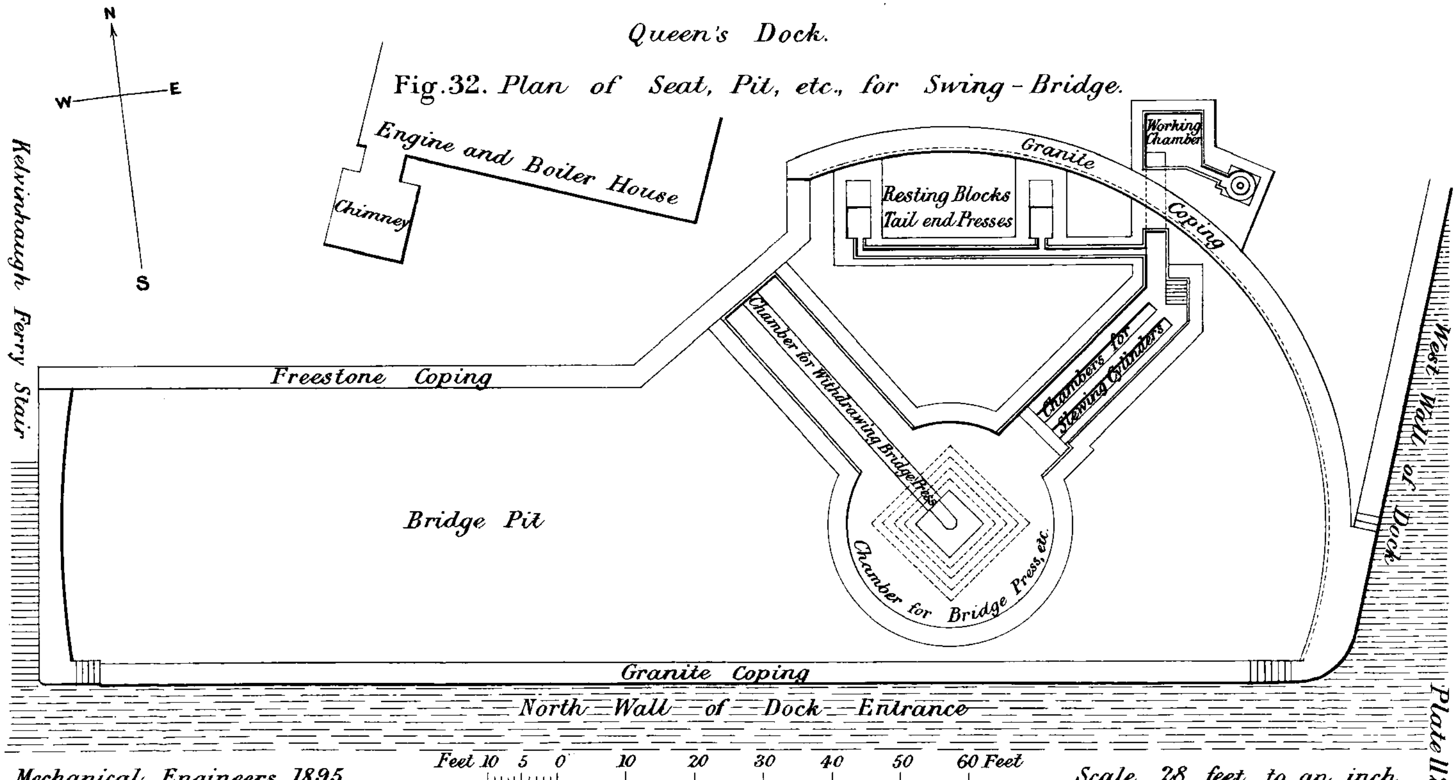
Fig. 31. *Plan.*



CLYDE NAVIGATION.

Queen's Dock.

Fig. 32. *Plan of Seat, Pit, etc., for Swing-Bridge.*



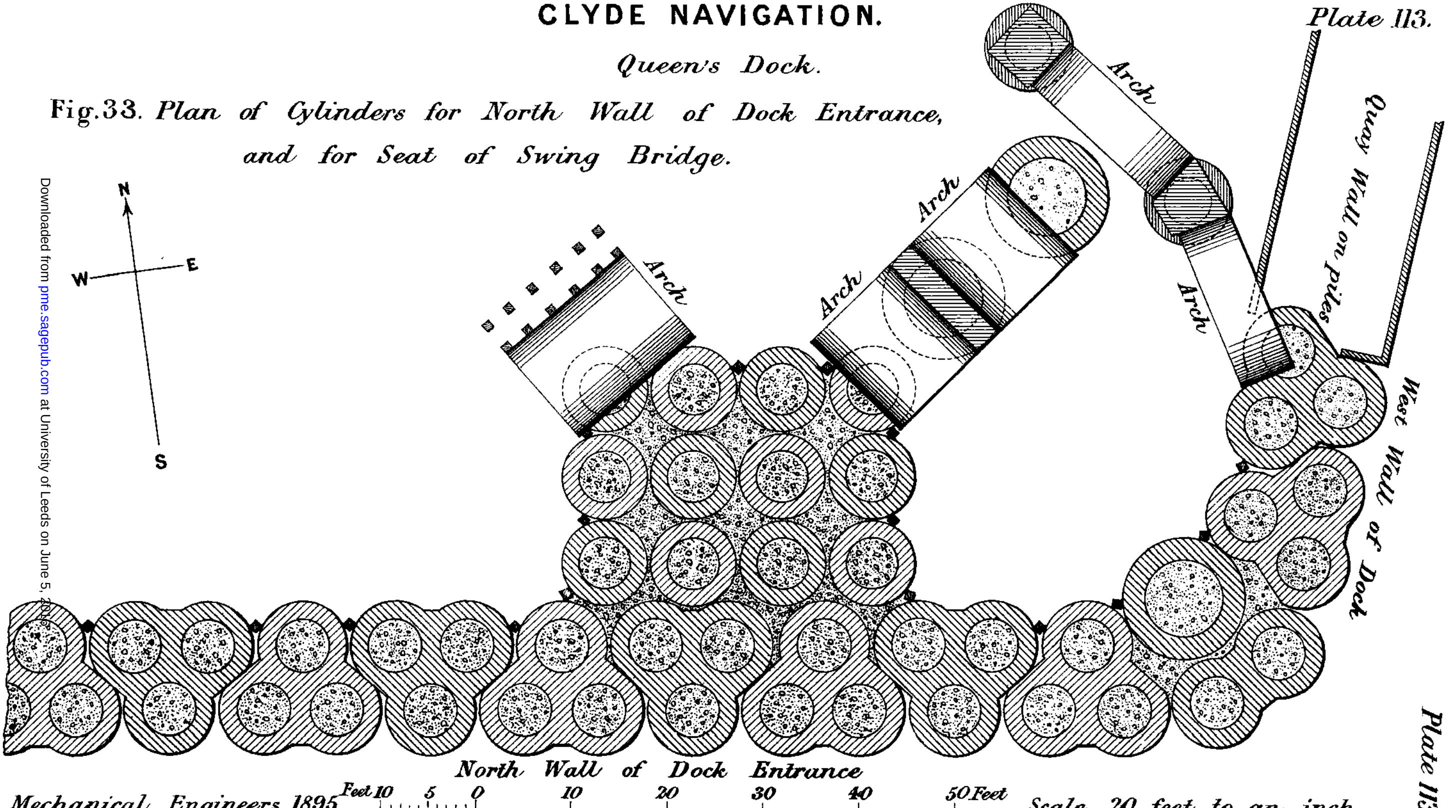
Scale 28 feet to an inch.

CLYDE NAVIGATION.

Plate 113.

Queen's Dock.

Fig. 33. *Plan of Cylinders for North Wall of Dock Entrance, and for Seat of Swing Bridge.*



Mechanical Engineers 1895.

Scale 20 feet to an inch.

Plate 113.

CLYDE NAVIGATION.

Queen's Dock.

Seat for Swing Bridge.

Fig. 34. *Section south and north.*

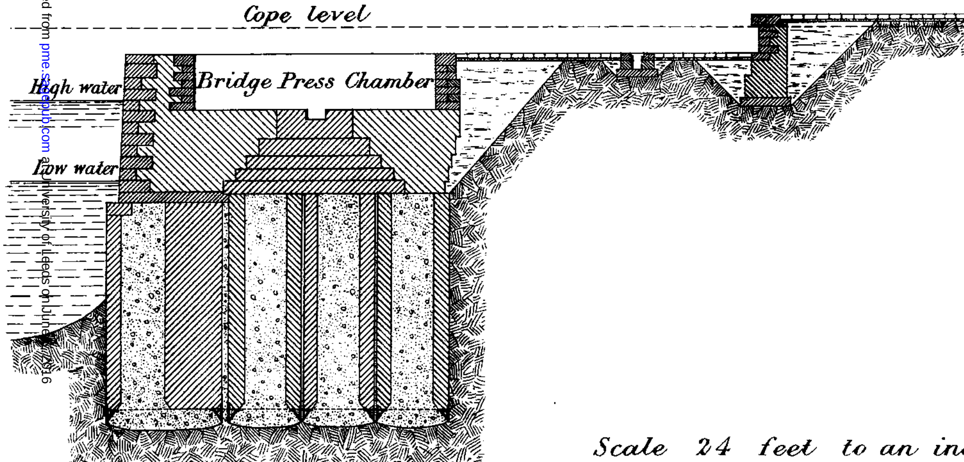
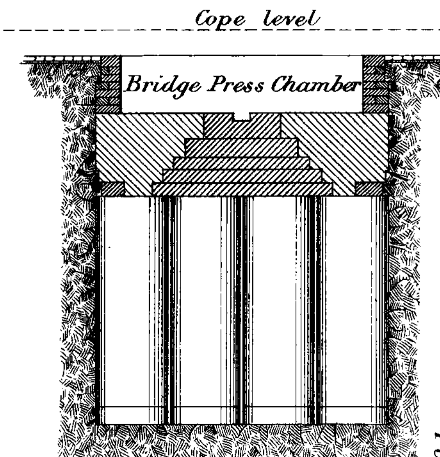


Fig. 35. *Section west and east.*



Scale 24 feet to an inch.

Feet 10 5 0 10 20 30 40 50 60 Feet

CLYDE NAVIGATION.

Plate 115.

Fig. 36.

Section of Quay Wall.

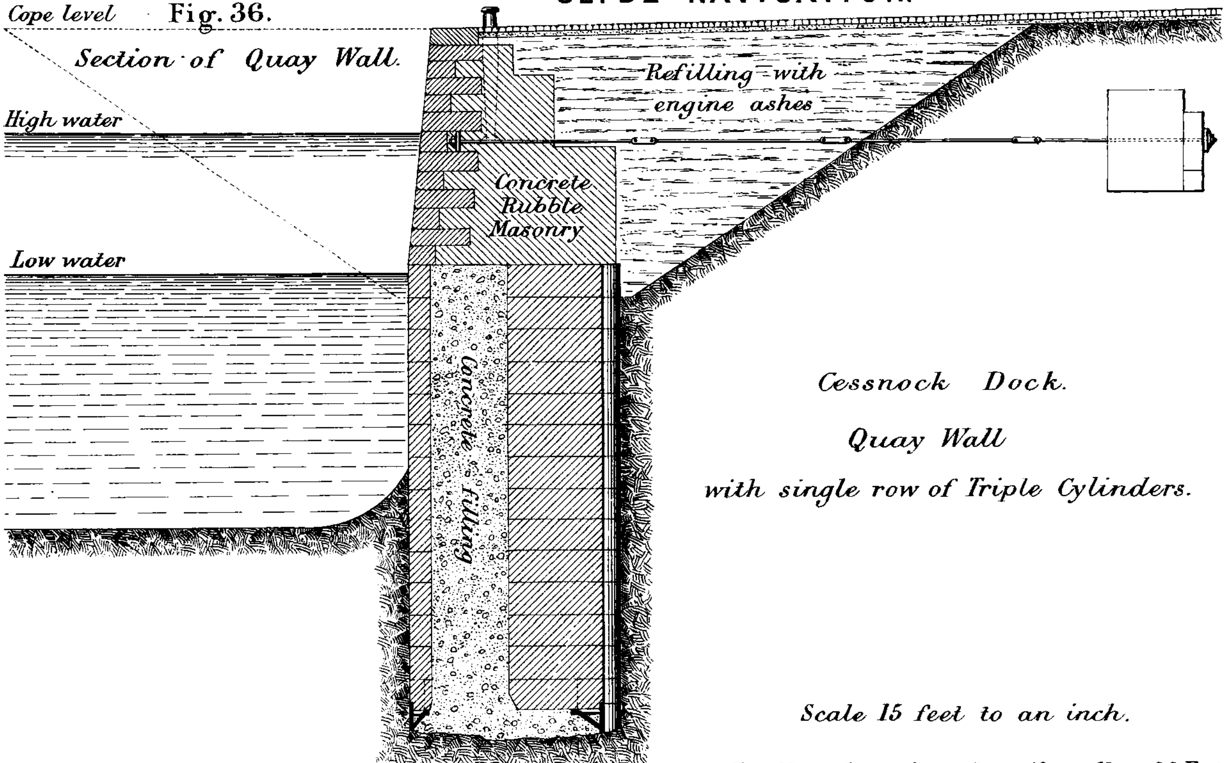
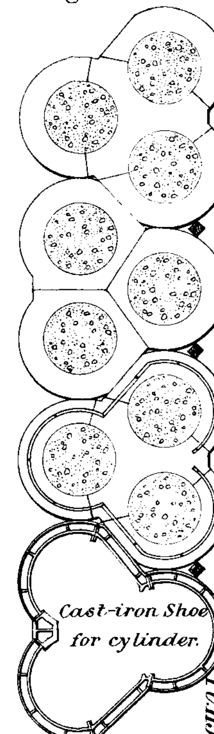


Fig. 37. Plan.



Cessnock Dock.

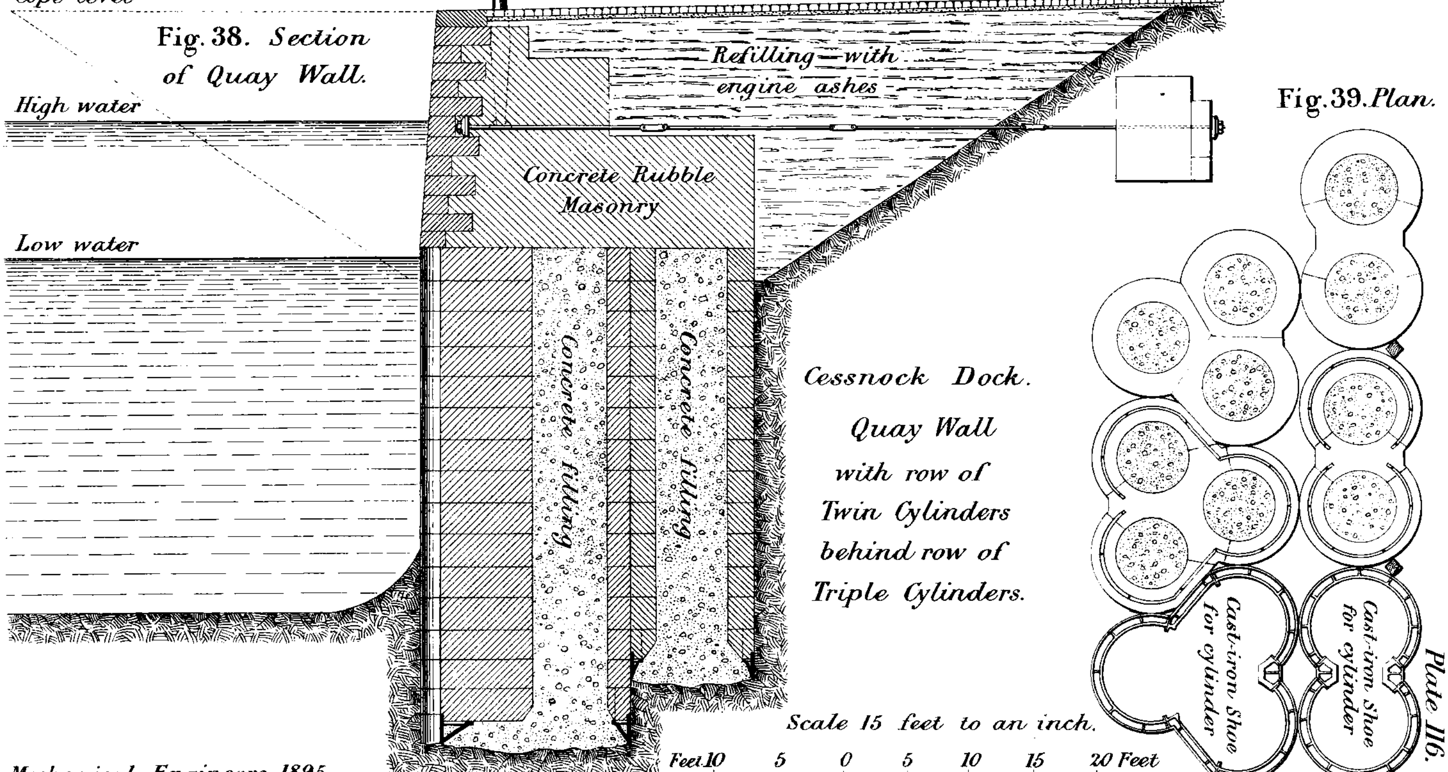
Quay Wall

with single row of Triple Cylinders.

Scale 15 feet to an inch.

Feet 10 5 0 5 10 15 20 Feet

CLYDE NAVIGATION.



CLYDE NAVIGATION.

Cessnock Dock. Seat for 130-ton Crane.

Fig. 40.

Vertical Section.

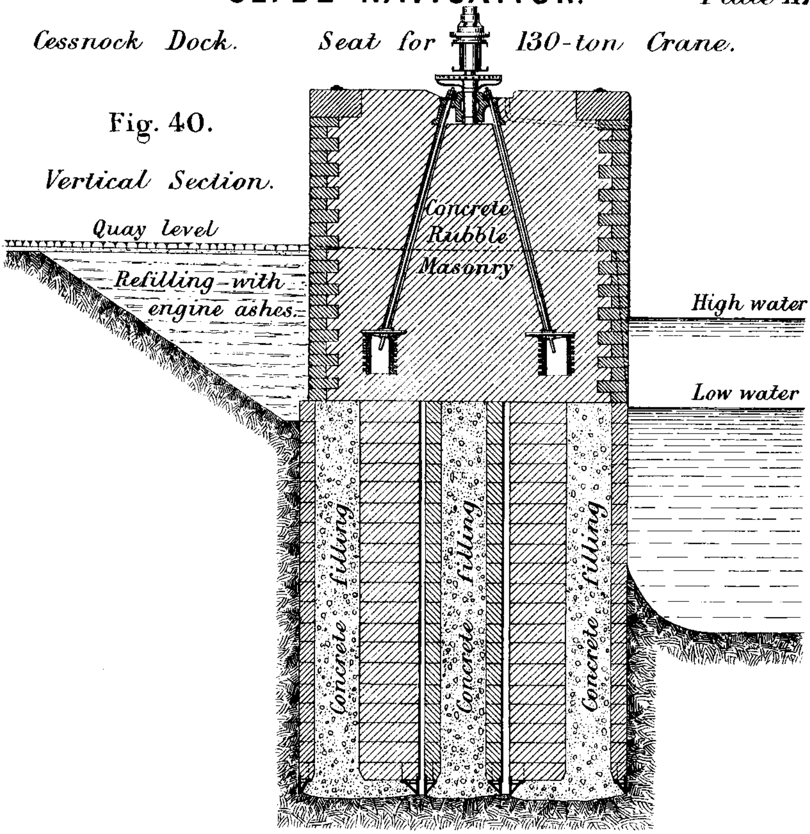
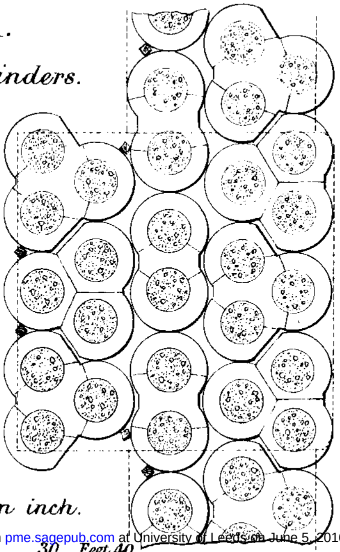


Fig. 41.

Plan of Cylinders.



Scale 24 feet to an inch.

Feet 10 5 0 10 20 30 Feet 40

Cessnock Dock. Seat for 130-ton Crane.

Fig. 42. Plan at top.

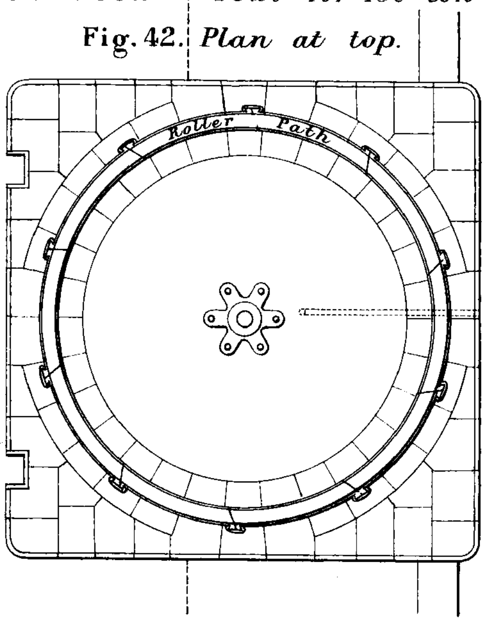
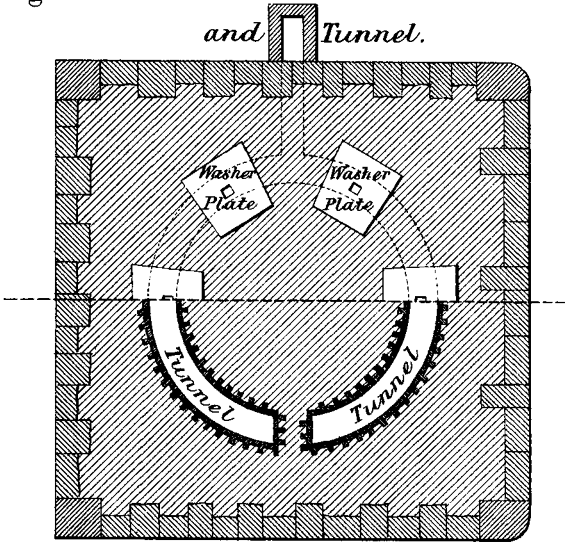


Fig. 43. Plans at levels of Washer-Plates and Tunnel.



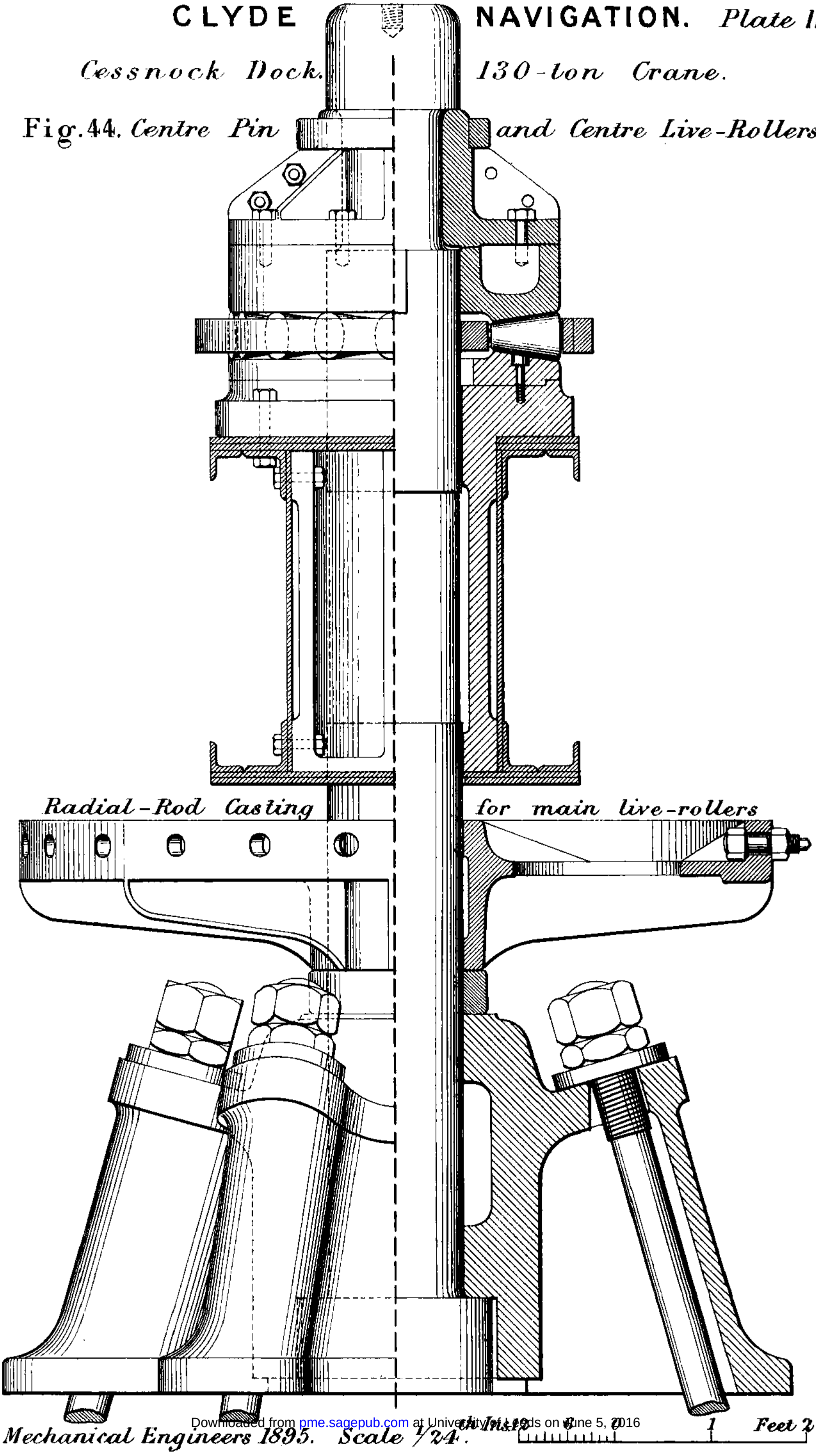
Mechanical Engineers 1895. Scale 16 feet to an inch.

Feet 10 5 0 10 20 30 Feet

CLYDE NAVIGATION. *Plate 119.*

Cessnock Dock. 130-ton Crane.

Fig. 44. *Centre Pin and Centre Live-Rollers.*



Mechanical Engineers 1895. Scale 1/24.

CLYDE NAVIGATION.
Plate 120.

Cessnock Dock. 130-ton Crane.

Fig. 45. *Plan of Centre Live-Rollers and Ring.*

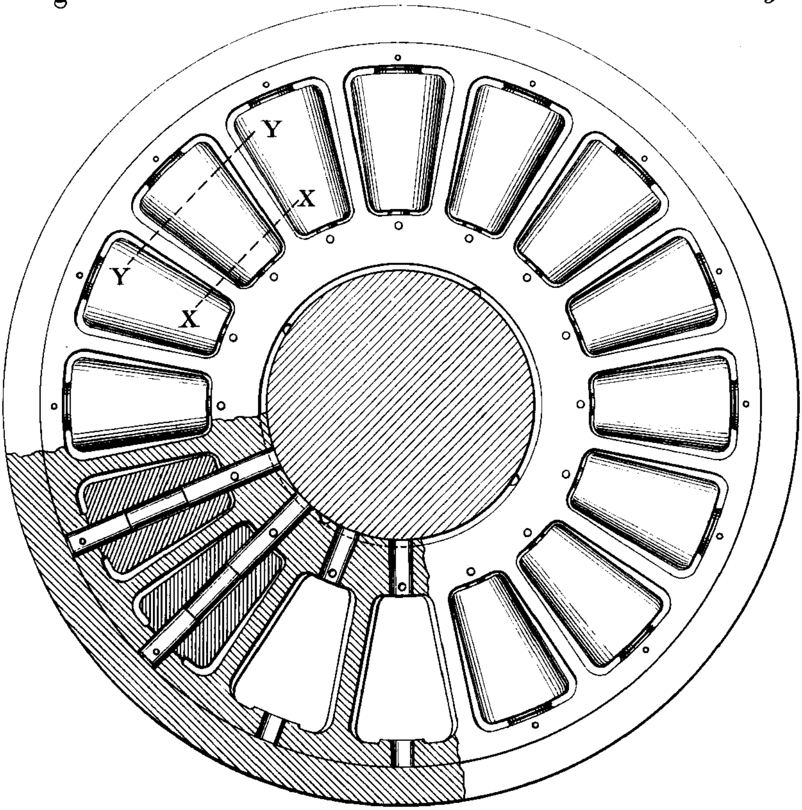


Fig. 46. *Elevation and Section.*

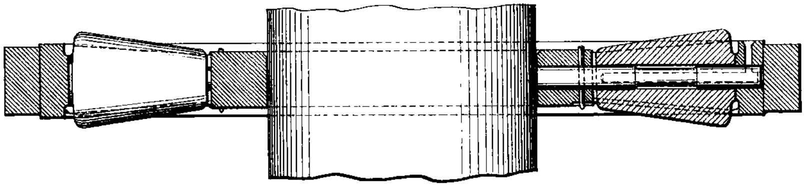
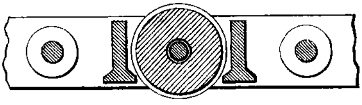


Fig. 47.

Section at X X.

Fig. 48.

Section at Y Y.



Mechanical Engineers 1895. *Scale 1/12th*

Inches 12 6 0 1 *2 Feet*